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A Case Study of Active Traffic Management: Safety Analysis and Operations Improvements Using a Queue Warning System

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A Case Study of Active Traffic Management: Safety Analysis and Operations Improvements Using a Queue Warning System

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Dedication

To those who believe in me. I love you all.

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Abstract

A Case Study of Active Traffic Management: Safety Analysis and Operations Improvements Using a Queue Warning System

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The University of Texas at Austin, 2011

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Active traffic management is a hot topic for addressing issues of highway congestion. It is the use of intelligent transportation systems to provide real time traffic information on highway conditions. In Austin, the segment of Interstate 35 between Riverside Drive and State Highway 71 experiences both congestion and safety issues. This report provides an introduction into the application of active traffic management through the use of a proposed queue warning system in the area. First, select crash data on the region is highlighted to present the safety conditions, particularly the type of collision and crash severity involved. Next, a proposed queue warning system design is described. This includes a description of the equipment used, methodology for system deployment, and expected outcomes. Finally, a computer simulation testing the operational performance of the queue warning system is performed using VISSIM, and the results are reported. This report aims to demonstrate the role that queue warning system and active traffic management may play in addressing metropolitan traffic needs.

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Chapter 1: Introduction

1.1 General Background

Highway facilities are an integral part of society. They are responsible for the mobility of millions of people for a variety of activities including work and leisure. They foster economic activity through trade and the movement of goods. During peak hours, highways in urban areas are often congested with queued vehicles traveling at slow to minimal speed. In addition to congestion being a high cost, traffic queues also pose an inherent safety issue. The nature of queued traffic often entails abrupt accelerating and braking, increasing the potential for rear end collisions and side swipes. The stop and go nature of queued traffic combined with the number of vehicles in close proximity is a significant safety problem on a congested highway.

Interstate 35 is the main north-south highway through Austin, Texas. It stretches in its entirety from the border town of Laredo, TX, to Duluth, Minnesota. As such, it is a major arterial for container transport from Mexico to the United States. In Texas, IH-35 runs through major cities including Laredo, San Antonio, Austin, and Dallas / Fort Worth. In Austin, IH-35 carries a high traffic volume that includes passenger cars and heavy trucks. The highway is also adjacent to a number of significant areas including downtown Austin, the University of Texas, Highway 71/290, and U.S. 183. It is also one of the major routes to Round Rock and Georgetown to the north, and San Marcos to the south. In 2009, Interstate 35 through Austin (from U.S. 183 to state highway 71) was identified to be the fourth most congested road in the state, with approximately 3.88 million hours of delay in the year (TXDOT, 2009).

Active traffic management (ATM) is a dynamic traffic system that deploys intelligent transportation systems (ITS) technology to address real time traffic scenarios. The ITS strategies include speed harmonization, queue warning, hard shoulder running, dynamic rerouting, travel time signs, dynamic rerouting signs, ramp meter control, and managed lanes. Each of these technologies utilizes detection equipment to gather real time traffic information. The information is in turn entered into a process algorithm that determines the most appropriate course of action, and the decision is subsequently displayed on changeable message signs to the vehicle. Active traffic management has gained traction among transportation officials in recent years in part from an attention shift to utilizing ITS technology to better manage existing highway facilities. It is one of four new topics included in the 2010 Highway Capacity Manual, although it is presented at a macro level as an introductory concept.

1.2 Problem Statement

Active traffic management has been gaining traction in the United States in recent years. Although it has been implemented and well documented in several highways in Europe, there remains a lot of uncertainty about its implementation on highways in the United States. According to the 2010 Highway Capacity Manual, active traffic management can be defined as a systems approach to optimizing the operational performance of the highway and street system through continuous monitoring of system conditions and dynamic control of the system (Dowling, 2009). While several ATM strategies such as managed lanes and ramp meters have been implemented throughout much of the nation, other strategies such as speed harmonization and hard shoulder running have seen limited deployment on selected highways. Naturally, numerous problems related to design and operations exist about applying active traffic management in the United States, as well as policy implications and challenges. Each ATM strategy is significantly different, and requires different levels of planning, design, and implementation.

According to the National Highway Traffic Safety Administration (NHTSA) two automobile collision types typically represent more than half of all documented auto collisions. In 2009, rear-end collisions and angle (side) collisions accounted for 31.5 and 25.8 percent of all crashes in the United States (NHTSA, 2010). A rear-end collision occurs when a vehicle strikes another vehicle from behind. The front vehicle is typically decelerating or static, and the vehicle in the back may be either accelerating or unable to come to a complete stop in time. Similarly, a side collision occurs when a vehicle strikes another vehicle from the side, often at an angle. In both cases, driver error probably plays a significant causative role, however, highway geometric characteristics may also play a role in many highway incidents.

In Austin, TX, Interstate 35 from the Colorado River bridge south to St. Elmo Road is of particular interest. This stretch of IH-35 has high traffic volume, significant vertical and horizontal curve changes, and limited sight distance. Additionally, this location has an unusually high number of rear-end collisions and side collisions; in 2009, rear end and sidecar collisions constituted of 75.7 percent of all documented crashes in the area (TXDOT, 2010). The Texas Department of Transportation is interested in the use of active traffic management and ITS technology to address the safety issues as a result of the heavy congestion and the geometric characteristics on this stretch of highway.

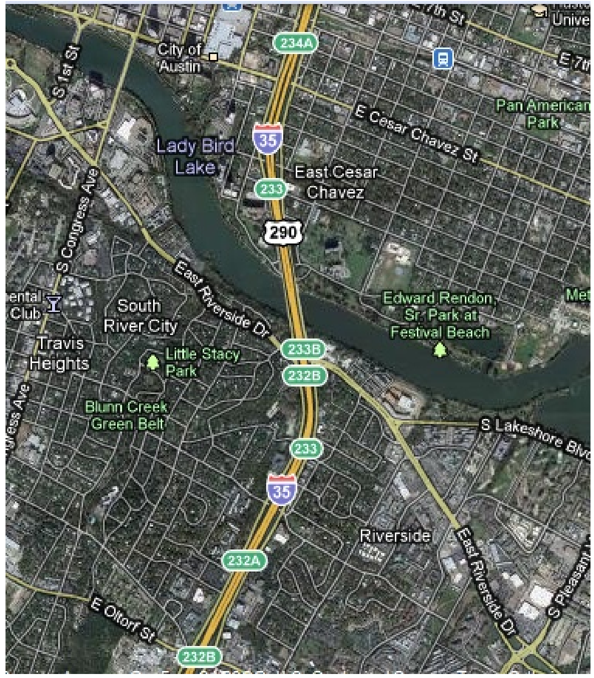


Figure 1: Map of IH-35 near the Riverside Drive [Source: Google Maps].

One of the ATM strategies considered for this segment is the use of queue warning systems to address both the congestion and safety conditions. A queue warning system is a system of sensor equipment and dynamic message signs with the intention of notifying vehicles of an upcoming queue. The intention of the queue warning system is to prevent additional queuing and delay, as well as to prevent unexpected braking or reductions in speed. Currently queue warning systems are primarily used in work zone conditions to warn motorists of reduced lanes and expected delays, as well as caution for workers and large construction equipment. Work zone queue warning systems usually include changeable message signs that display warnings about the upcoming work zone, with a caution to reduce speeds and expect delay. There is interest in expanding the role of queue warning systems beyond work zones to improve safety from everyday congested scenarios.

1.3 RESEARCH OBJECTIVE

The purpose of this paper is to evaluate the safety potential of a queue warning system as part of active traffic management on Interstate 35 in Austin from the Colorado River to St. Elmo's Road. First this paper will present a literature review on the different ITS strategies in active traffic management. Each strategy will be given an in-depth look into its design and operation, as well as potential benefits and examples of real world practice. The paper will look at highway systems using ATM in Europe, as well as those in the United States currently deploying the strategies; these systems will be discussed for their effectiveness along with their benefits and costs. The paper will then examine the geometric and traffic conditions of the highway segment, as well as the existing infrastructure that may be used for vehicle detection and information dissemination.

A proposed queue warning system is introduced for the highway segment. The design for the queue warning system will be discussed, such as the field equipment, detection algorithm, graphical user interface, and dynamic message signs for information dissemination. The queue warning system layout will be described, as well as how the system can be integrated into real warning and control systems. The potential effectiveness, benefits, and costs of the queue warning system are highlighted, along with the potential safety improvements on the selected highway segment. Finally, system recommendations and further research needs are mentioned in the conclusion.

The focus of this research is twofold. First, this paper investigates the traffic and safety conditions relative to the geometric conditions of a particular segment of IH-35. Namely, the research is focused on the extent to which the geometric conditions (horizontal and vertical curves, sight distance) contribute to the unusually high incident rate on this section. The second part of this research is centered on proposed active traffic management to address the needs of the highway facility, in this case safety and collision warning. The increasing role of ITS technology on U.S. highways highlights the steps needed for ATM deployment and implementation. Faced with increasingly limited options to address the pressing needs of a growing metropolitan area such as Austin, active traffic management is a very real alternative that transportation officials must consider. The proposed queue warning system on IH-35 is one example of active traffic management in the Austin district; with this research TXDOT officials may feel compelled to investigate further deployment of such strategies on other highways.

Chapter 2: Literature Review

2.1 SPEED HARMONIZATION

Speed harmonization is the use of real time variable speed limits in order to reduce speed differentials particularly when traffic demand approach highway section capacity. Speed harmonization employs detection equipment to sense real time vehicle speed, volume, and occupancy. The detection equipment may be either invasive such as inductive loop detectors and magnetometers, or non-invasive such as radar or video detection technology. This information is entered into a process algorithm that determines the appropriate speed limit. The speed limit is continually updated at specified intervals to reflect the existing conditions on the highway facility.

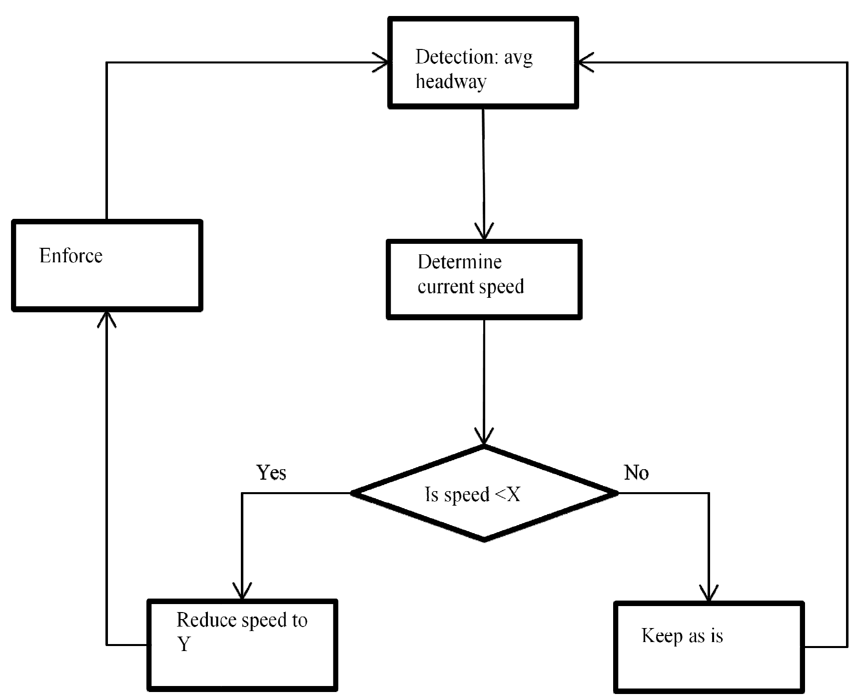


Figure 2: Sample Basic Algorithm for Variable Speed Limit.

The strategy is based on basic traffic flow theory with relationships between traffic volume, average speed, and density (occupancy). The fundamental equation for a vehicle stream can be described in the following Greenshields multidimensional relationship:

$$q = uk$$

Where q = volume, veh/hr; u = space mean speed, mi/hr; and k = density, veh/mi (Greenshields, 1935). In low volume free flow conditions, mean speeds are often greater than the posted speed limit, and range of speeds represented by the standard deviation is large. That is, time and distance headways are large, allowing drivers to choose their speeds with little interaction among vehicles. As the highway becomes congested, the average speed decreases from free flow conditions to and significantly, interaction among vehicles increase dramatically. Variability among driver desired speeds when demand is near capacity may cause drivers with high desired speeds to decelerate suddenly reacting to slower moving vehicles and these speed changes may precipitate "shock waves" leading to a "stop and go" condition. Speed harmonization, that is, reducing posted speeds as volume approaches capacity typically causes a fraction of drivers to reduce speeds to the new lower posted limit and since distance headways are small if only a fraction of all drivers assume the new speed, the entire traffic stream tends to assume the new speed. Experimentation, primarily in Europe, has shown that this effectively reduces speed variability reducing the frequency of sudden speed changes creating a more stable flow pattern under higher volumes, at least, delaying onset of "stop and go."

Speed harmonization reduces the speed limit based on the current density to increase the volume and traffic flow through the facility. By lowering the speed limit during increased density, the traffic volume is comparable to flowing conditions at a higher speed and lower density (Papageorgiou, 2008). Speed harmonization provides a uniform traffic flow across a highway segment that is advantageous for safety applications. Additionally, research exists that suggest passengers prefer a moving vehicle to a stationary one, even if the vehicle is moving at a lower speed (Zhang, 2009).

Figure 3: Variable Speed Limits in Missouri (Source: Missouri DOT).

The most notable benefits of variable speed limits are safety improvements. Safety improvements stem from the uniform flow of the highway segment rather than the abrupt, uncertain nature of stop-and-go traffic (Fudala, 2010). In one pilot study of variable speed limits in a work zone, vehicles were shown to reduce lane changes and number of stops when the strategy was deployed (Borrough, 1997). Meanwhile, crash reductions have been noted at numerous sites. On the M25 in England, the use of variable speed limits in conjunction with dynamic message signs and loop detectors resulted in a decrease in traffic accidents by 28 percent during 18 months of operation (Abdel-Aty et.al, 2008). At the same time, speed harmonization has been shown to have a minimal impact on crash risk on highway segments where the volume to capacity ratio is very high (National Traffic Safety Board, 2001).

2.2 QUEUE WARNING

Queue warning is the use of variable message signs to warn moving vehicles as they approach a stopped queue. Queues occur on highways when traffic demand exceeds capacity and the flow process becomes "stop and go." They often form in congested areas, but may also form in areas where there is a change in roadway characteristics, such as at a work zone area or in areas of limited sight distance. Queued traffic often poses a heightened risk for rear-end collisions, as vehicles may be unable to brake in time. Queue warning systems differ from static traffic warning signs in that they are automatically activated in response to a current queue condition. The most common problem with queue warning is queue variability. While a certain highway segment may have a recurring queue during peak hours, the length of the queue at a particular time is often uncertain and highly variable (NTSB, 2001).

A queue warning system senses current roadway conditions to warn upstream motorists as they approach a queue. Detection equipment (both invasive and noninvasive) is used to sense when and where vehicles are beginning to queue. Identifying the location of the queue is critical for the queue warning system, as this will determine where dynamic message signs upstream will be deployed. The design of the queue warning system is largely dependent on the problem type to be addressed; problem types range from sight distance constraints to recurrent congestion to construction maintenance zones to incidents. Queue warning systems are recommended to be installed in consideration for highly variable queues (Wiles et. al, 2005).

Figure 4: Queue Warning System in Canada (Source: ITS Canada).

Queue warning is often used in conjunction with speed harmonization in practice because of their similar design configurations and equipment use. Queue warning is a major component of Germany's speed harmonization system. Results from a pilot queue warning system in Germany showed fewer accidents and reductions in accident severity, as well as more uniform driver behavior (Sparmann, 2006). In the Netherlands, the combination of queue warning and speed harmonization has been associated with a 15 to 25 percent decrease in primary accidents, a 40 to 50 percent decrease in secondary accidents, and a 4 to 5 percent increase in throughput (Middelham, 2006).

2.3 Hard Shoulder Running

Hard shoulder running is the use of the shoulder lane as an additional lane to provide temporary additional capacity during peak periods of traffic. The shoulder lane is usually the outside lane, although the inside lane may also be considered if there is adequate width. Unlike speed harmonization and queue warning, hard shoulder running is focused primarily on relieving congestion and improving travel time. As such, the strategy is primarily considered in areas of high congestion with limited expansion options. Hard shoulder running has seen limited application in the United States, and is more frequently used as part of a managed lane system in Europe.

One example of hard shoulder running is the use of bus only shoulders on select highway segments in metropolitan areas. The buses are given strict restrictions as to when shoulder use is permitted; these restrictions include a low average speed on the main highway, reduced speed limits on the shoulder, and when to enter and leave the shoulder. The most notable use of bus only shoulder lanes is in the Minneapolis / St. Paul metropolitan area. The program consists of over 14 routes, 400 buses, and 271 miles of wide highway shoulders designated for bus use during peak congestion periods (MNDOT, 1998). The most notable benefits from bus only shoulder lanes are improvements in travel time (albeit not as significantly as one would imagine) and increased schedule reliability and on time performance. Another pilot bus only shoulder program in Cincinnati resulted in estimated travel time savings ranging from 5 to 20 minutes (Oki Regional COG, 2008).

Hard shoulder running requires numerous design considerations, although currently there is no standard or uniform guideline. The shoulder should be both structurally stable and meet the same pavement strength and depth as the regular freeway. The shoulder is only allowed for use during certain times of the day, and there is often a speed limit that is less than the main roadway. For the bus only shoulder lanes in Minneapolis / St. Paul, some of the design requirements include a minimum width of 10 feet, a stopping sight distance of 250 feet, a maximum vertical clearance of 14 feet, and a maximum superelevation of 0.05 (MNDOT, 1998). Additionally, monitoring equipment and enforcement are critical to the success of hard shoulder running. In order for the shoulder lane to be operable like a regular highway lane, it must be clear of debris, and freeway personnel must be able to respond quickly to remove any obstructions that may appear during its time of use.

Figure 5: Hard Shoulder Running on the M42
(Source: Department for Transport, UK).

Benefits for hard shoulder running include a temporary increase in highway capacity, which results in congestion reduction and travel time improvements. In one pilot project, the use of hard shoulder lanes during peak periods on a congested highway in Germany resulted in a 20 percent increase in capacity as well as improved traffic flow and significant decreases in congestion (Riegelhuth and Pilz, 2007). On the M42 highway in the United Kingdom, the use of hard shoulder running and variable speed limits has been shown to reduce average travel times by 25 percent (Middelham, 2006). Hard shoulder running is also an attractive alternative for state transportation departments in lieu of new construction of additional facilities. The cost of stabilizing and converting a shoulder lane, as well as operations and maintenance, is significantly less than an equivalent lane expansion problem (USDOT, 2007).

Figure 6: Hard Shoulder Running in Virginia (Source: Lee).

The most obvious concern with hard shoulder running is safety. Numerous studies have been undertaken to determine if hard shoulder running may result in an increase in collisions and incidents. On one highway in Germany, highways without hard shoulder running were found to have 25 percent more incident rates compared to highways with the strategy. This highway also saw a 68 – 82 percent in congestion, as well as a 9 percent increase in average speed (Kellerman, 2000). In Houston, TX, a test program with narrower lanes and shoulder use on US-59 resulted in a significant reduction in collisions (McCasland, 1978). Meanwhile in California, a project converting four lanes to five lanes resulted in increases between 10 and 11 percent in incident frequency, with a smaller increase for a conversion between 5 and 6 lanes. However, researchers argue that the increase in incident frequency is a result of displaced congestion from the increased capacity (Bauer et. al., 2004). Safety concerns have inspired numerous design requirements including emergency refuge areas every 500 meters, maximum response time for emergency vehicles, adequate advance sign distance, and restricted use for trucks (Lee et. al., 2007).

2.4 Dynamic Rerouting

Dynamic rerouting is the use of variable message signs to direct traffic to alternate routes under conditions of limited access such as congestion. Similar to other active traffic management strategies, dynamic rerouting is dependent on detection equipment to gather real time traffic information. Dynamic rerouting differs from queue warning and speed harmonization in that it can require numerous algorithms and complex interactions with the traffic management center to identify and assign an alternate route. It does not refer to rerouting traffic for a singular occasion such as a sporting event, but instead refers to the real time process of diverting vehicles across a highway network.

Identifying the type of rerouting to recommend is dependent on the problem type to be addressed. For both recurring congestion and incidents, the strategy relies on dynamic traffic assignment, although it is used differently in each case. Dynamic traffic assignment is the method of determining and assigning a number of vehicles to a specific link at a particular time under changing conditions. It uses both real time traffic data and archived sources in various models to calculate origin-destination behaviors and choices. The Federal Highway Administration is currently working on numerous dynamic traffic assignment projects for a real time traffic estimation and prediction system (TrEPS). Additionally, dynamic traffic assignment has the potential to assist transportation agencies in incident management by analyzing the disruption to the existing urban transportation network and assessing the effectiveness of the incident response (Sisiopiku et. al., 2007).

Potential applications for dynamic rerouting include reductions in travel time, improvements in incident response and management, and reductions in congestion. Dynamic rerouting requires a network of detection equipment and processors to determine the appropriate traffic assignment. While current detection equipment is readily able to gather real time traffic information, many of the algorithms and decision processes required for making traffic assignments are not able to process all of the incoming information (Aved et. al., 2007). As such, the role of dynamic rerouting in active traffic management is still very limited in practice beyond simulation.

2.5 TRAVEL TIME SIGNS

Travel time signs utilize dynamic message signs to provide travel time information to a downstream destination. Traffic management centers depend on numerous data sources for travel time estimation, including counts from detectors, historical time-dependent origin-destination data, and static O-D data. Travel time is often calculated using a process algorithm of information collected from speed measurements taken from detection equipment at two locations. In a survey of transportation agencies with the strategy, travel time updates range from within 2 minutes to 30 minutes, although a majority is updated within 5 minutes (Dudek, 2008).

Figure 7: Different Travel Time Signs in Washington, California, and Ontario, Canada (Sources: WSDOT, Caltrans, FHWA).

Travel time signs are already used on many highways in the United States to provide approximate travel time to a particular location based on existing road conditions. They are often the primary ITS application of variable message signs. States that have implemented travel time signs include Washington, New York, Colorado, Delaware, Florida, California, and Illinois, to name a few. At the same time, the type of reporting done on a travel time sign varies; a sign may report travel time to a road or landmark, travel time to a city, travel time along with distance to the destination, travel time and time of calculation, event description and travel time, and travel time reported in a 2-3 minute range (ENTERPRISE, 2007). In addition to displaying travel times, dynamic message signs are also used for amber alerts, roadwork updates, incidents, weather updates, and special events, to name a few. The dynamic message signs are used for other events typically during non peak hours.

There is a heightened interest in research regarding travel time reliability. Travel time reliability is concerned with the level of consistency that a transportation service (such as a highway facility) may provide. One feature of travel time reliability is primarily concerned with minimizing sources of unreliable travel times, which include traffic incidents, work zones, weather, demand fluctuations, special events, traffic control devices, and inadequate base capacity (Cambridge Systematics, 2003). The procedures used for travel time estimation and the reliability measures undertaken vary greatly, and rely on either archived data or traffic counts. The majority of state DOTs have their own standards for message design and display.

2.6 Ramp Meter Control

Ramp meters limit the number of vehicles allowed to enter a freeway per unit time. It is most often applied to single lane entry ramps, however, if ramp geometry allows, an onramp may be separated into two or more lanes. Vehicles are given permission to systematically access the ramp and enter the freeway by a controlled signal light that in the case of multi-lane ramps alternates between the lanes. In addition to controlling the number of vehicles that are allowed to enter the freeway, ramp meter control can eliminate vehicle platoons resulting from an upstream traffic signal. This may reduce abrupt speed changes on the highway entrance, a safety improvement which may affect the number of rear end collisions (Chaudhary and Messer, 2000).

Ramp metering is a well known and established practice, and can be found on many highways in numerous metropolitan areas throughout the United States.

Figure 8: Ramp Meter Control (Source: AZDOT).

Different metering approaches exist for timing and control. Ramp meter control can be local (or isolated) control, or system-wide (or coordinated) control. This is dependent on the scope of the ramp meter strategy, whether or not control is desired to address conditions at one specific location or if the aim is for problems that extend from ramp to adjacent ramp. Signaling types include pre-timed metering, traffic responsive metering, local traffic responsive, and system-wide traffic responsive (Jacobson et. al., 2006). Three types of ramp meter strategies exist: single lane one car for green, single lane multiple cars for green, and dual lane metering. Design guidelines for ramp meter control vary by state. Placement guidelines exist for the detection equipment deployed on the entrance ramp and the use of signing and signal devices.

2.7 Managed Lane System (HOV and HOT)

Managed lane systems refer to systems of high occupancy vehicle (HOV) lanes and high occupancy toll (HOT) lanes. Managed lanes often exist as a separate set of lanes with controlled access within an existing highway facility, traveling in the same direction but physically separated from the normal lanes. In HOV lanes, cars must have a minimum number of passengers in the vehicle (usually 2 or 3) to be able to use the facility. HOT lanes allow single passenger vehicles to access the HOV lanes with a toll charge. Additionally, express lanes are similar to HOT lanes, but all vehicles (both multiple and single occupancy) must pay a toll. Tolls are often collected electronically through the use of radio frequency identification and toll tags.

The type of managed lane deployed is dependent on the lane management strategy and intentions of the system. According to the FHWA, lane management strategies can be classified as pricing, vehicle eligibility, or access control. For a pricing strategy, toll lanes or value priced lanes may be considered. The vehicle eligibility strategy looks at HOV lanes, truck lane restrictions, and the use of HOV lanes by other vehicle groups. Express lanes and reversible lanes (lanes in which the direction of traffic flow change depending on the time of day) may be used for the access control strategy (FHWA, 2004). While each strategy may seem to be fairly well defined, the managed lane system becomes increasingly complex as real time traffic management becomes a bigger issue. Additionally, more transportation agencies are considering the conversion of HOV lanes into HOT lanes.

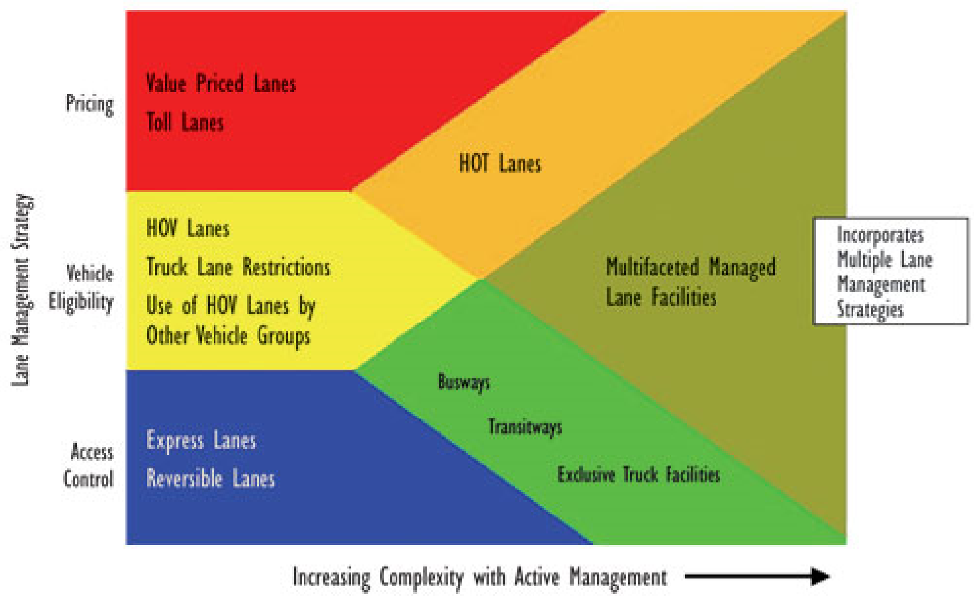


Figure 9: Managed Lane Applications (Source: FHWA).

While HOV lanes have been around for decades, there has been recent interest in the conversion of HOV lanes into HOT lanes. HOT lanes offer benefits including travel time reliability and revenue generation. They provide vehicles with the option of predictable travel conditions in lieu of congested conditions, and maximize the use of managed lanes which include HOV lanes (Sas et. al., 2007). Other benefits include new revenues to support the construction of the HOT lanes or other initiatives, traffic service improvements on congested parallel highway main lanes, performance reliability during peak periods, faster highway trips for bus rapid transit, and more (Sas et. al., 2007). Converting HOV lanes into HOT lanes is one consideration of managed lanes that may take advantage of underperforming HOV lanes.

Much of the research in managed lanes is centered on value pricing (also known as congestion pricing). Value pricing often involves real time traffic information to both manage demand and generate revenue. It is different from a conventional toll road in that the toll price varies according to the time of day. Whereas a flat toll is primarily used to generate revenue, the intent of a variable toll is to reduce demand on the particular lane. Price determination is largely determined from real time or historically based data of the regular highway lanes. The type of data used may have an impact on the traffic conditions, especially with unpredictable incident occurrences. Nevertheless, both types of traffic data are used to price managed lanes.

Chapter 3: Active Traffic Management Application

This chapter presents several case studies of active traffic management applied on international and domestic highways. Each highway system utilizes different combinations of ATM strategies to address the unique needs. Performance results of each system are also mentioned, as well as any safety consequences and findings from the ATM implementation. Much of this chapter is derived from a *Synthesis of Active Traffic Management Experiences in Europe and Related Articles* and *Active Traffic Management: the Next Step in Congestion Management* (Mirshahi et. al., 2007), but other synthesis and state of the practice documents are also referenced.

This chapter is separated into three parts: international case studies, domestic case studies, and ATM integration benefits and challenges. First, the country's transportation plan and policy will be discussed, along with an overview of the national highway system. Different ATM strategies on key highways are highlighted, as well as performance results from strategy implementation. The end of this chapter discusses the benefits, challenges, and lessons learned from implementing active traffic management as evidenced from the case studies detailed here.

3.1 ATM IMPLEMENTATION AND APPLICATION IN EUROPEAN COUNTRIES

3.1.1 United Kingdom

The United Kingdom contains several motorway systems utilizing different strategies as part of active traffic management. These motorways include the M25 and the M42. The M25 is a 188 km (117 miles) ring road that nearly surrounds London. According to the national Highways Agency, it is one of Europe's busiest motorways, with nearly 200,000 daily vehicles (Highways Agency). Meanwhile, the M42 is an 88.5 km (55 mile) road that runs from

Bromsgrove in Worcestershire to Ashby-de-la-Zouch in Leicestershire. Many roadway operations are run through public private partnerships.

The National Traffic Control Center oversees a system of 1,700 CCTV; 4,450 traffic sensors; and 350 dynamic message signs every day throughout the year (Highways Agency). It oversees traffic and roadway conditions for the entire nation, and is divided into seven regions. Incidents are handled by the Traffic Office Service, which patrols motorways to respond to incidents and clear the affected road. Different methods of disseminating real time traffic information include the Highway Agency Information Line, dynamic message signs, Internet updates, and interactive online programs that allow for travel time and roadway predictions (Harbord, 2006).

The M25 utilizes variable speed limits on its London orbital. The system, which has been active since 1995, spans 22.6 kilometers (14 miles), and contains variable speed limit signs every 1 km (0.6 mile) interval. Loop detectors are located every 500 m (0.3 miles), and CCTV is connected throughout the entire network. The speed limit is changed from 70 mph to 60 mph when there are more than 1,650 vehicles per hour per lane, and further lowered to 50 mph when this number exceeds 2,050. Enforcement is done using photo radar (35 mm). Key results from speed harmonization include high driver compliance with the VSL signs and a 10-15 percent reduction in accidents (Robinson 2000). Additionally, plans are underway to add hard shoulder running on key sections of the highway, with construction scheduled to begin after the 2012 Olympics.

The M42 has several ATM strategies including variable speed limits, queue warning, and hard shoulder use along a 17.7 km (11 mile) stretch. The technologies deployed on the M42 include lightweight gantries, lane control signals, dynamic speed limit signals, dynamic message signs, digital enforcement technology, CCTV, enhanced lighting, roadway sensors, emergency roadside telephones, and emergency refuge areas (Highways Agency). Emergency refuge areas with call boxes are located every 500 meters (1,640 feet) to allow vehicles to pull over from the hard shoulder lane. The highway system operations performance includes a 7 to 9 percent increase in capacity as a result of hard shoulder running. Travel time has improved ranging from 9 to 24 percent as a result of speed harmonization (Highways Agency). Additionally, this segment of M42 saw a reduction in personal injury accidents from 3.17 to 1.83 per month (Highways Agency). Following the success of hard shoulder running, the Highways Agency announced plans to further expand the strategy on other motorways in the nation, including the north-south motorways M1 and M6.

3.1.2 Greece

Greece is an example of a nation with a developing modern highway system with private funding involvement. Even today, the majority of Greece's roadways consist of two-lane undivided roadways. While it has highways designated as part of the EU Trans-European Transport Network program, Greece has not funded a modern highway facility completely with public dollars. It primarily uses public private partnerships to finance transportation projects.

The Attiki Odos toll motorway is 65 km (40.4 miles) long and extends from Elefsina to Markopoulo. Also known as the Attica Tollway, it opened in 2004 and runs through Athens and the airport. It is equipped with closed circuit television cameras, dynamic message signs, lane control signals, and pavement sensors. The tollway utilizes electronic toll collection, and offers discounts to frequent users. The toll is a flat fee for passenger vehicles and light commercial vehicles (more for heavy commercial vehicles), and is for the length of the entire roadway.

Detection equipment including inductive loops, microwave sensors, and telemetry software are utilized to gather traffic conditions and predict roadway demand (Koutsoukos, 2006).

The highway is connected to a traffic management center that operates 24 hours a day, 7 days a week. The traffic management center is responsible for numerous activities, including monitoring operations, reporting extraordinary traffic conditions, emergency management, road maintenance and clearance activities, and disseminating real time traffic information on dynamic message signs (Highways Agency). Attica Tollway also has a well defined incident management strategy that consists of detection, verification, response, and clearance. Incidents are detected using CCTV, emergency roadside telephones, 24 hour patrol units, or personnel at the traffic management center. The personnel are responsible for ensuring quick responses to incidents that may increase delay on the tollway.

Strategies deployed on the Attica Tollway include variable speed limits and managed lanes as part of the highway's active traffic management. Variable speed limits are utilized at the beginning of tunnels on the tollway to notify vehicles of different speed limits in the tunnel compared to the rest of the facility. Additionally, unique managed lane strategies such as bus only lanes and Olympic lanes are used on major arterials. In bus only lanes, autobuses have the exclusive roadway during certain time periods. Olympic lanes refer to exclusive lanes used to transport Olympic related personnel (athletes, spectators, referees, officials, and such) between event venues. These two managed lanes are located on arterials, as the urban freeways in Greece are not currently experiencing congestion levels meriting ATM strategies (Mirshahi et. al., 2007).

3.1.3 Germany

Germany's regional operations have two main goals for their motorway networks: safety and mobility. Safety components include harmonizing traffic flow, providing warnings to vehicles, and the dissemination of real time traffic information (Sparmann, 2006). Meanwhile, maintaining and improving mobility includes fully utilizing the existing road network and deploying various strategies to temporarily increase road capacity (Sparmann, 2006). Public private partnerships play a major role in managing Germany's highway operations.

The center of motorway operations is headquartered at Traffic Center Hessen. Germany emphasizes a proactive traffic management strategy, stressing line control, incident management, network optimization, construction site management, and traffic information as part of its strategy management tenet. German highways are equipped with data gathering technology such as inductive loop detectors, floating cars, video cameras, and other sensor types. Key traffic management strategies include the dissemination of real time traffic information, speed harmonization, queue warning, and hard shoulder running.

Germany has a strong focus on the dissemination of real time travel information as part of its national transportation policy. It has a national goal of serving 80 percent of all trips on the national motorway system with real time travel information by 2010 (Bolte, 2006), though it remains to be seen if these parameters have been met. To maximize comprehension, design guidelines for dynamic message signs advocate the use of internationally understandable legends, as little text as possible, as much text as unavoidable, and preferred symbols and signs of the Vienna Convention (Bolte, 2006). Radio is also used to transmit the traffic information; the publicly available Traffic Message Center of the Radio Data System conveys real time data using digitally encoded radio messages. The messages are in turn utilized in in-vehicle navigation systems to provide unique routing schedules and improved route calculations beyond the scope of the dynamic message sign.

Speed harmonization has existed on congested highways in Germany since the 1970s. Overhead gantries for the speed limit display are located every 1 km (3,300 feet) apart, but may vary. Notable benefits from variable speed limits include a slight increase in capacity (Pilz, 2006) and reduced accident rates. On the A5 motorway between Bad Homburg and Frankfurt/West, the implementation of speed harmonization has been associated with a 27 percent reduction in accidents with heavy metal damage and a 30 percent in reduction in crashes with personal injury (Sparmann, 2006).

Hard shoulder running is deployed in conjunction with speed harmonization on several motorways in Germany. They have existed since 1996, and there are nearly 200 km (125 miles) of hard shoulder lanes throughout the country. Hard shoulder running is permitted with a reduction in travel speeds. The temporary lane is closely monitored by the traffic management center using CCTVs to ensure they are free from obstruction and the speed limits are enforced. Results from the speed harmonization – hard shoulder running system include up to 20 percent reduction in travel time and a 25 percent temporary increase in freeway capacity (WSDOT, 2007).

Germany also employs numerous queue warning systems on its motorways. The queue warning systems vary in appearance, scope, and complexity. One queue warning system, known as COMPANION, is a roadside information system that deploys flashing lights on beacon posts to notify vehicles of unexpected upstream conditions such as collisions or congestion. The lights vary in frequency and flashing patterns, brightness, color, and warning lengths depending on the location, condition of the incident. This system was installed on the outside shoulder for 18 km

(11.2 miles) along the A92. Meanwhile, another queue warning system in Germany uses a small roadside VMS with flashers to indicate the length and location of the queue. As mentioned, the national transportation policy strongly emphasizes comprehensive communication of the queue warning on the message signs using minimal wording and simple imagery. Benefits gathered from the German queue warning system include fewer incidents, reduced incident severity, closer headways, greater uniformity on all driver speeds, and a slight increase in capacity (Bolte, 2006).

Figure 10: Small DMS Sign for Queue Warning System (Source: ITS Magazine).

3.2 ATM Implementation and Application in the United States

3.2.1 Washington

The state of Washington is in the process of implementing a series of active traffic management strategies on their freeways. These strategies include a speed harmonization and queue warning system that is automatically activated based on upstream traffic conditions, along with travel time signs to critical highway junctions. The project is centered on IH-405, IH-90, and IH-5 near Puget Sound.

Since 1997, Washington has one of the earliest implementations of speed harmonization in the United States. The earliest variable speed limits were deployed on the IH-90 Snoqualmie Pass. They were intended for improving safety by informing motorists of road condition and weather information. The speed limits are adjusted by computer, and confirmed via control center operator. Thirteen variable speed limits are deployed over 40 miles (64.4 km), although only 17 miles (27.4 km) are in operation during the winter months. The posted speed limit is 65 miles (104.6 km) per hour, and decreases in 10 mph (16.1 kmph) increments depending on the physical road conditions – 55 mph (88.5) when traction tires are advised, 45 mph (72.4) when traction tires are required, and 35 mph (56.3) when chains are required. The variable speed limits are enforced (Robinson, 2000).

In 2010, WSDOT completed construction and began operating a variable speed limits and queue warning system on IH-5 in Puget Sound between IH-90 and S.R. 518. Previously, WSDOT was using ATM strategies including ramp metering, traffic management centers, congestion sensors, real time traffic information, electronic message signs, HOV lanes, incident response vehicles, and traffic cameras (WSDOT, 2007, 2009). According to a feasibility study of ATM published in 2007, the implementation of speed harmonization and a queue warning system in Puget Sound would result in a 30 percent and a 15 – 25 percent reduction in injury collisions, respectively (WSDOT, 2007). In addition to the speed harmonization and queue warning system, WSDOT is also interested in the use of hard shoulder running on freeways in the near future.

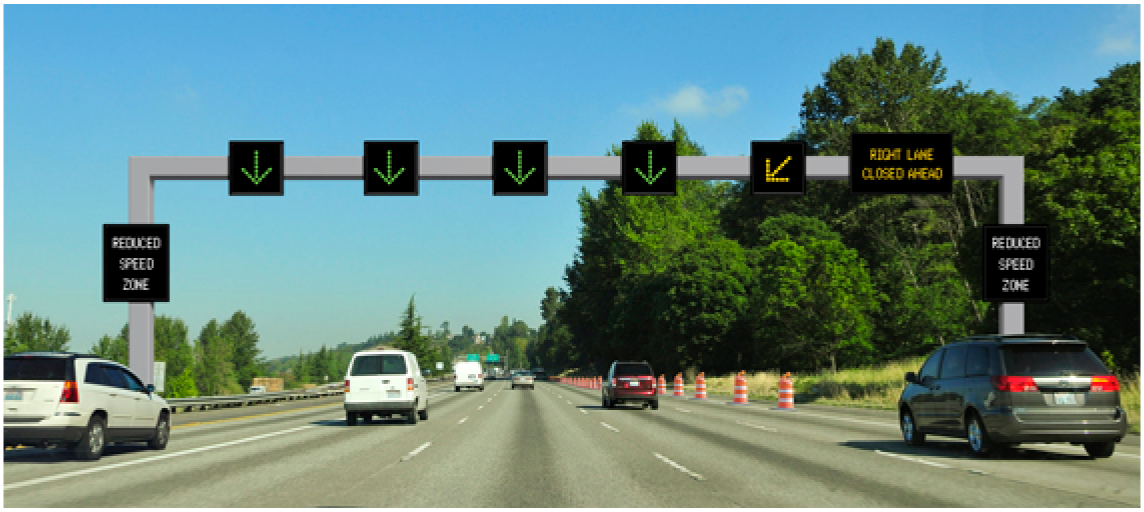


Figure 11: Visualization of Speed Harmonization and
Queue Warning System on IH-5 (Source: WSDOT).

3.2.2 Virginia / Washington, D.C.

The Washington, D.C. metropolitan area deploys a network of managed lanes, hard shoulder running, and variable speed limits. Interstate 66 is one of the major highways leading into Washington, D.C. from northern Virginia and as such, the facility is often overtaxed during peak periods. Temporary shoulder use and managed lanes take place on IH-66, between U.S. 50 and IH-495. The highway consists of 3 lanes in each direction; the general main lanes are 12 feet wide, the interior shoulders are 8 – 12 feet wide, and the exterior shoulders are 11 feet wide (Ungemah and Kuhn, 2009).

Temporary shoulder use on IH-66 began in 1994 to allow the leftmost lane to serve as an HOV lane. The shoulder lane operates in the peak-direction during peak hours for general traffic. During hard shoulder running, emergency refuge areas (4 eastbound, 5 westbound) are used to allow vehicles to pull over for emergencies. The right shoulder lane is permitted for use by the general traffic during the peak periods of 5:30 AM – 11 AM, and 2 PM – 8 PM. The shoulder lane may also be used during traffic incidents or construction as additional capacity (Kuhn, 2010). A safety analysis using a negative binomial regression model and crash data from

2002 to 2004 revealed that the use of the shoulder lane did not have a statistically significant effect on crash frequency during the peak hour (Lee et. al., 2007).

Figure 12: Hard Shoulder Running Sign in Washington D.C. (Source: Ungemah).

3.3 QUEUE WARNING: CASE STUDIES

The following section details several case studies of queue warning systems implemented in different states. The queue warning systems serve a variety of purpose, ranging from exit ramp spillback, to congestion warning, to accident warning. Nevertheless these systems all notify approaching vehicles of a standing queue and the need to decrease speed in advance. These case studies can be found in the Texas Transportation Institute's *Advanced Warning of Stopped Traffic on Freeways: Current Practices and Field Studies of Queue Propagation Speeds* (Wiles et. al., 2005).

3.3.1 California

The California Department of Transportation utilizes queue warning systems as a response to a high collision rate on particular freeway segments compared to other segments on the freeway. One example of this is the use of a queue warning system for exit ramp spillback, which occurs when a queue forms at an exit that is longer than the lane and spills over into the general highway lane. Safety concerns and collision risks arise when vehicles using the highway lanes are unaware of the slowly moving vehicles trying to exit in the general highway lane, and abruptly reduce their speed. When exit ramp spillback at Winchester Road on IH-15was causing vehicles to back up into the main lanes and subsequently a high collision rate, Caltrans officials placed a static queue warning sign north of the exit (Hall, 2001).

Another example is the outlined plan of a proposed queue warning system to address collision concerns with change in grade, horizontal curvature, and limited sight distance. The proposed queue warning system was in response to the high collision rates that occurred 1 mile on each side of a particular mountain peak on Highway 17. The proposed system included loop detectors spaced every 600 feet in each direction; two dynamic message signs; communication links between detectors, controller, and the message signs; hardware for moisture and fog detection; and software to automatically post messages during inclement weather and congested conditions (SRRTC, 2000).

The Caltrans Automated Warning System is a series of dynamic message signs and speed monitors that provide both visibility and speed warnings to motorists along busy traffic corridors. Located in Caltrans District 10, the system notifies vehicles of stopped or slow traffic ahead that may otherwise not have been observed. The message displayed on the signs is automatically triggered by type of driving condition that the weather and traffic sensors detect. For example, when traffic speeds are between 11 – 35 mph, the message “Slow Traffic Ahead” is shown. When traffic speeds are between 1 – 10 mph, the message “Stopped Traffic Ahead” is shown. Concurrently, when visibility is between 0 – 100 feet, the signs display “Dense Fog Ahead.” When visibility is between 201 – 500 feet, the signs read “Foggy Conditions Ahead.” The speed warnings override the fog warnings in the case of a collision in inclement weather (CALTRANS, 2000).

3.3.2 Florida

The Florida Department of Transportation utilizes a temporary traffic management system to address congestion and queued vehicles as a result of a long term congestion project on Interstate 95. The system consists of 19 portable trailers that contain cameras, speed sensors, and variable message signs to display incident and delay warnings. Unlike other ITS strategies, this program is temporary and portable, requiring no construction. Communication is sent wirelessly, and the system is either on trailers or temporarily mounted for the duration of the project. Additionally, FDOT is leasing rather than purchasing all of the equipment in the traffic management system, for upgrades as technology advances (McGinness, 2001).

3.3.3 Texas

Since 1995, the San Antonio metropolitan area operates the TransGuide Intelligent Transportation System for congestion scenarios. In queue warning, TransGuide is able to determine both the start and end of the queue. Dynamic message signs display several ITS messages upstream of heavily congested areas about the location and travel time of the queue, as well as other warnings. The first message displayed contains information about the start and end of the queue, and the second message may provide travel time to particular locations, a caution warning, or advice to minimize lane changes. Operators closely monitor the dynamic nature of the queue warning messages and modify them as needed (Wiles et. al., 2002).

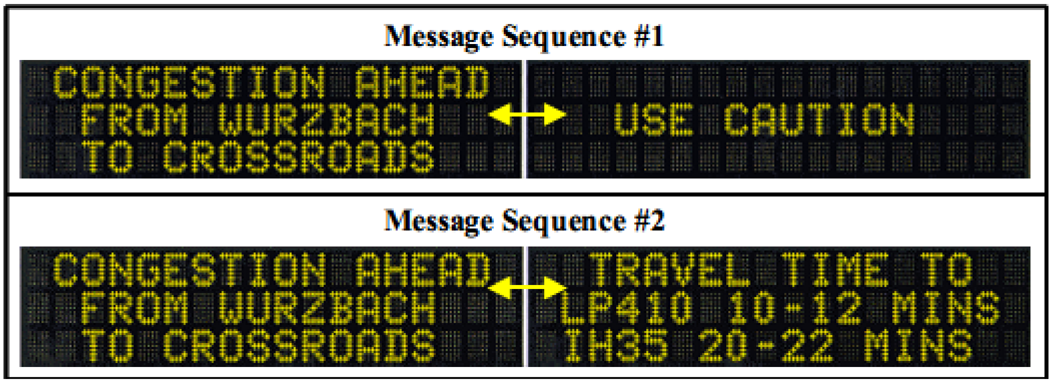


Figure 13: San Antonio TransGuide Congestion Warning Example Messages (Source: Farello).

The Fort Worth area uses both static and dynamic queue warning systems to notify approaching motorists of queues. TransVision, the regional ITS management system, uses dynamic message signs to warn motorists of a queue spillback on an exit to a frontage road that is very close to a signalized intersection. For example, dynamic message signs were used near an exit to Hulen Mall during the holiday season. The message read "WATCH FOR SLOW TRAFFIC AT HULEN EXIT," and operators had the additional ability to activate flashing yellow lights. Meanwhile, static queue warning signs are used on highway segments that have limited geometric conditions that may result in the formation of queues. This can be seen on the IH-20 frontage road near Bryant Irving Road in response to vertical crest curve sight distance concerns. Here these signs read "CAUTION WATCH FOR SLOW TRAFFIC AHEAD" (Wiles et. al., 2002).

3.4 ATM System Integration Benefits and Challenges

This chapter presented several case studies of international and domestic active traffic management systems. Different strategies were highlighted, along with varying reasons for their implementation and design. These reasons vary from highway geometric conditions to higher collision rates to persistent congestion issues. Performance results of the ATM systems (both operations and safety) are reported when available from the corresponding transportation agencies.

The benefits from active traffic management systems depend largely on the strategy implemented and the issue the strategy is trying to address. The FHWA document *Active Traffic Management: the Next Step in Congestion Management* (Mishahi et. al., 2007) lists potential benefits that may be gathered from different ATM strategies. A table detailing ATM strategies and the various potential benefits they may provide can be found below. From this table, the potential benefits for queue warning include decrease in primary incidents, decrease in secondary incidents, decrease in incident severity, more uniform speeds, decreased headways, more uniform driver behavior, increased trip reliability, reduction in traffic noise, reduction in emissions, and reduction in fuel consumption.

Active Traffic Management Strategy	Potential Benefits												
	Increased throughput	Increased capacity	Decrease in primary incidents	Decrease in secondary incidents	Decrease in incident severity	More uniform speeds	Decreased headways	More uniform driver behavior	Increased trip reliability	Delay onset of freeway breakdown	Reduction in traffic noise	Reduction in emissions	Reduction in fuel consumption
Speed harmonization	X		X		X	X	X	X	X	X	X	X	X
Temporary shoulder use	X	X							X	X			
Queue warning			X	X	X	X	X	X	X		X	X	X
Dynamic merge control	X	X	X			X		X	X	X	X	X	X
Construction site management	X	X							X		X	X	X
Dynamic rerouting and traveler information	X		X	X				X	X			X	X
Dynamic lane markings	X	X							X				
Automated speed enforcement			X		X	X		X	X			X	X

Table 1: Potential Benefits of Active Traffic Management (Source: Mirshahi et. al.).

At the same time, the case studies gave insight into the different issues and challenges that may arise with ATM systems. No highway project is without integration challenges and difficulties. The FHWA report *Efficient Use of Highway Capacity Summary* (Kuhn, 2010) details key issues with the integration of ATM systems. These issues include:

- Design
- Traffic control devices
- Pavement markings

- Performance
- Maintenance
- Enforcement
- Incident response
- Training
- Costs
- Liability issue
- Legal issues
- Public outreach and education (Kuhn, 2010).

The integration benefits and challenges demonstrated by the case studies in this chapter highlight the complexity and variety of such traffic management systems. For the scope of Interstate 35 at Riverside, the particular components that need to be examined are the geometric characteristics, traffic volumes, and safety conditions of the highway segment. First, however, a closer inspection of the use for frontage roads must be examined to maximize the highway system's potential to address operations and safety concerns. The next chapter will focus on reviewing previous thesis work regarding frontage roads and Interstate 35.

Chapter 4: Geometric Characteristics and Safety Conditions

4.1 Geometric Characteristics

4.1.1 Horizontal Curve

Interstate 35 extends approximately 2.7 miles between Riverside Drive and St. Elmo Road. From St. Elmo Road to Woodland Avenue, IH-35 follows in a straight line. The freeway curves northwest for an arc length of slightly more than 0.5 miles between Riverside Drive and Woodland Ave. Beyond Riverside Drive, IH-35 follows again in a straight line.

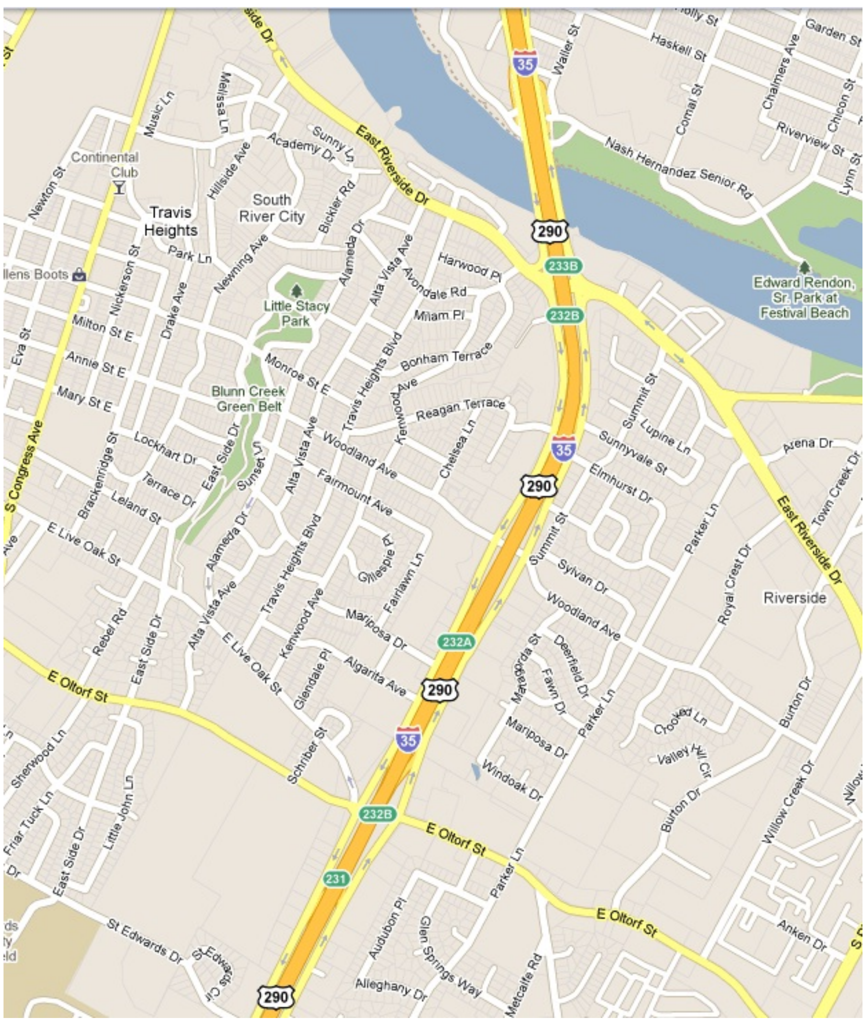


Figure 14: Interstate 35 between Riverside Drive and Oltorf Street (Source: Google maps).

4.2 Traffic Volume Conditions

Congestion is a persistent problem in Austin and Central Texas. According to the 2009 traffic count from the Capital Area Metropolitan Planning Organization (the most recent), AADT for this Interstate 35 highway segment consisted of 171 to 177 thousand vehicles per day for the segment between State Highway 71 and the Colorado River (CAMPO, 2009). The Annual Average Daily Traffic represents the number of vehicles that use the roadway on a typical non-summer work day. Meanwhile, AADT for State Highway 71 near IH 35 was between 100 and 139 thousand vehicles per day.

According to the Texas Transportation Institute's most recent Urban Mobility Report, in 2009 Austin experienced 39 hours of delay per auto commuter, ranking 15th in the nation for large areas (population between 1 and 3 million) (TTI Urban Mobility, 2011). Using collected 2009 traffic data, the Texas Department of Transportation ranked Interstate 35 between SH 71 and US 183 as the fourth most congested road in Texas, with an annual cost of $84.4 million (delay and fuel cost) and a congestion index of 1.41. This means that a trip that would normally take 1 hour during peak time will take 1.41 hours on IH35 (TXDOT, 2010).

4.3 Safety Conditions

According to a TXDOT crash data summary on Interstate 35 between Riverside Drive and Woodward Street, the nearly two mile segment experienced a total of 713 crashes between 2007 and 2009 (no information was available for 2010). Of the 713 crashes, 317 (44.5 percent) were non-injury or property damage only, 234 (32.8 percent) possible injury, 146 (20.5 percent) non-incapacitating injury, 12 (1.7 percent) incapacitating injury, and 4 (0.6 percent) fatalities. The types of collisions include 1 head on, 87 run off road / fixed object / overturn, 91 side swipe, 433 rear end, 17 left turn, 73 angle, and 11 other (TXDOT, 2011). Five hundred and twenty four of the 713 crashes, or 73.5 percent, are side car or rear end collisions. The source for the crash information is the Crash Records Information System database, which the Texas Department of Transportation maintains.

Meanwhile from the same report, the half mile segment between Woodland Avenue and Riverside Drive saw a total of 250 crashes between 2007 and 2009. This segment is particularly notable for having a high degree of horizontal curvature. Of these crashes, 110 were non-injury or property damage only, 89 possible injury, 46 non-incapacitating injury, 3 incapacitating injury, and 2 fatalities. Types of collisions consisted of 29 run off road / fixed object / overturn, 29 sideswipe, 148 rear ended, 9 left turn, 31 angle, and 4 other (TXDOT, 2011).

The next chapter analyzes the safety data on Interstate 35 to determine if the highway geometry between the Colorado River and St. Elmo Boulevard plays a role in the number of accidents.

Chapter 5: Safety Data Analysis

5.1 Introduction

This section looks at the safety data on Interstate 35 for 2009 as provided from the Texas Department of Transportation. This project analyzes the recorded accidents on IH-35 in Texas in 2009 to determine if highway geometry plays a role in the accident frequency of the highway segment between Riverside Drive and SH-71. Safety data plays a role in understanding the type of accidents and vehicle behaviors that must be noted and observed on a particular roadway segment. This project looks at the relationship between crash frequency and several variables including road alignment, crash severity, and type of collision. For a proposed queue warning system, the presence of an increased number of accidents gives insight into the appropriate selection and placement of signage.

5.2 Background

TXDOT maintains accident data on all Texas highway facilities that are maintained by the state including interstates, state highways, US highways, farm to market roads, and such. This database is known as the Crash Records Information System. The accident data contains over a hundred very specific attributes about each incident. The specifics include weather condition, latitude / longitude, highway number, milepost, number of vehicles, and types of injury. The data also contains different vehicle attributes (make, model, year), and person data (age, gender, seat position).

For this project, TXDOT provided CRIS reports between 2003 and 2009. Each CRIS report contains the crash reports and a lookup reference. The lookup reference was used for some variables that are measured and kept on the nominal scale (e.g. a certain number represented a certain city). Additionally, not all of the variables had complete entries in each cell. For the purpose of the analysis, the crash reports with missing entries in the variable in question were omitted when the variables were subjected to frequency and crosstabs reports. While it is ideal to look at the crash reports for each year to better understand the scope of the safety concerns, due to time constraints this project only reviewed the information from 2009, the most recent year. The statistical software SPSS was used to maintain the crash reports, as well as provide the analysis for this report.

The variables chosen for the safety analysis are:

- City
- Crash severity
- Road alignment
- Traffic control
- Collision (type)
- Incapacitating injury count
- Non-incapacitating injury count
- Possible injury count
- Non-injury count
- Unknown-injury count
- Total injury count
- Death count
- Curve type

These crash variables were analyzed using frequency analysis and crosstabs along the entire Interstate 35 section between Riverside and SH-71. This report presents some of the more significant findings from the descriptive statistics.

5.3 CITY

Accidents along IH-35 in Texas may occur in a city or rural environment. The CRIS crash report identified 88 cities that had crashes in 2009 (one of the variables was 'UNKNOWN', and made up less than 0.03 percent of the total). The top cities consist of:

City	Frequency	Percentage
Austin	18891	14.4
Dallas	16588	12.6
Fort Worth	14578	11.1
San Antonio	18195	13.8
Rural Denton County	7796	5.9
Laredo	4776	3.6
Round Rock	4540	3.5
New Braunfels	2917	2.2
San Marcos	2809	2.1
Temple	2581	2.0
Waco	3125	2.4
other	34637	26.3

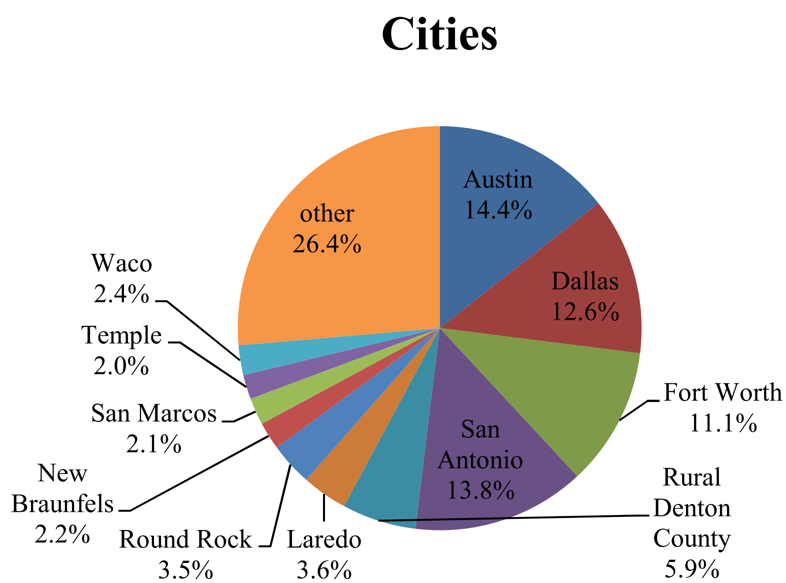


Table 2: City Crash Statistics along IH-35 in Texas

If Round Rock was included as part of the Austin metropolitan area, the region would have 17.9 percent of the total number of accidents along IH-35 in 2009, second to the Dallas-Fort Worth region (23.7 percent).

Meanwhile, the crash distribution shows that the IH-35 section between Riverside and Sh-71 experienced the highest number of crashes in Austin in 2009. Only the accidents that occurred in Austin were considered. The accidents were assigned to certain sections based on their geographic location. The sections are classified based on their primary road reference mark number that is perpendicular to IH-35. Each section is approximately 2.5 – 3 miles long, and the numbers increase northward along the section. Section E encompasses the segment of IH-35 between Riverside and US-290.

	Section	Frequency	Percent
A	State Highway 45 toll and below	10	.1
B	Onion Creek to SH-45 toll	209	1.4
C	Slaughter to Onion Creek	638	4.4
D	SH-71 to Slaughter	1148	7.9
E	Riverside to SH-71	3707	25.4
F	East 32nd to Riverside	3660	25.0
G	St. John's Avenue to East 32nd	2207	15.1
H	Braker to St. John's Ave	1384	9.5
I	Parmer to Braker	978	6.7
J	Parmer and alove	670	4.6
Total		14611	100.0

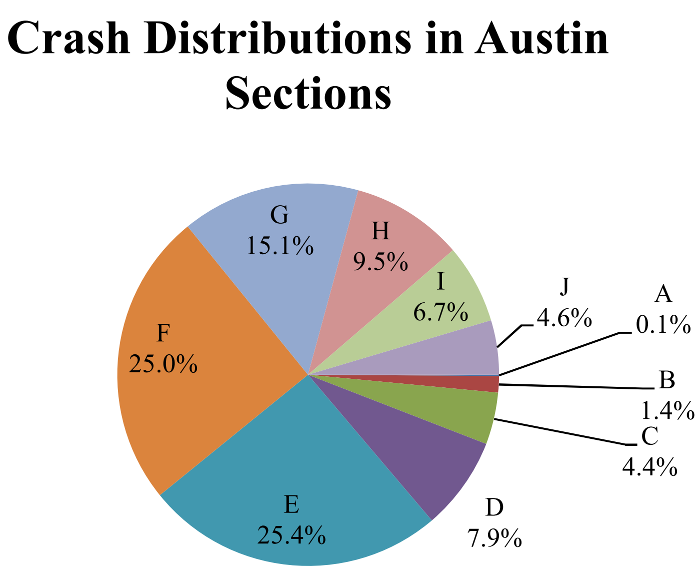


Table 3: Crash Frequencies on Various IH-35 Sections in Austin

From the chart it can be seen that section E, the stretch of IH-35 between SH-71 and Riverside Drive, has the most accidents, with 25.4 percent. Section 78, between Riverside Drive and Martin Luther King Drive, is the next highest with 25 percent.

5.4 CRASH SEVERITY

Crash severity refers to the extent of injuries sustained and is grouped into six categories: unknown, incapacitating injury, non-incapacitating injury, possible injury, fatal, and not injured. An incapacitating injury refers to an injury that prevents the injured from performing normal activities such as walking or driving. A fatal injury occurs when someone involved in the crash dies as a result from the injuries sustained, and may include pedestrians. In the CRIS database, the injury counts do not include pedestrians because the freeway counts are for injuries experienced on the freeways (in a similar fashion, the CRIS also does not report accidents that occur on the frontage roads). Exact definitions may vary per state, and TXDOT does not have any official definitions regarding these injuries.

Crash Severity	Frequency IH-35 in Texas	Percent	Frequency IH-35 between Riverside and US-290 / 71	Percent
Unknown	1381	1.1	29	.8
Incapacitating injury	2772	2.1	78	2.1
Non-incapacitating injury	16243	12.4	901	24.3
Possible injury	31456	23.9	1077	29.1
Fatal	830	.6	18	.5
Not injured	78751	59.9	1604	43.3
Total	131433	100.0	3707	100.0

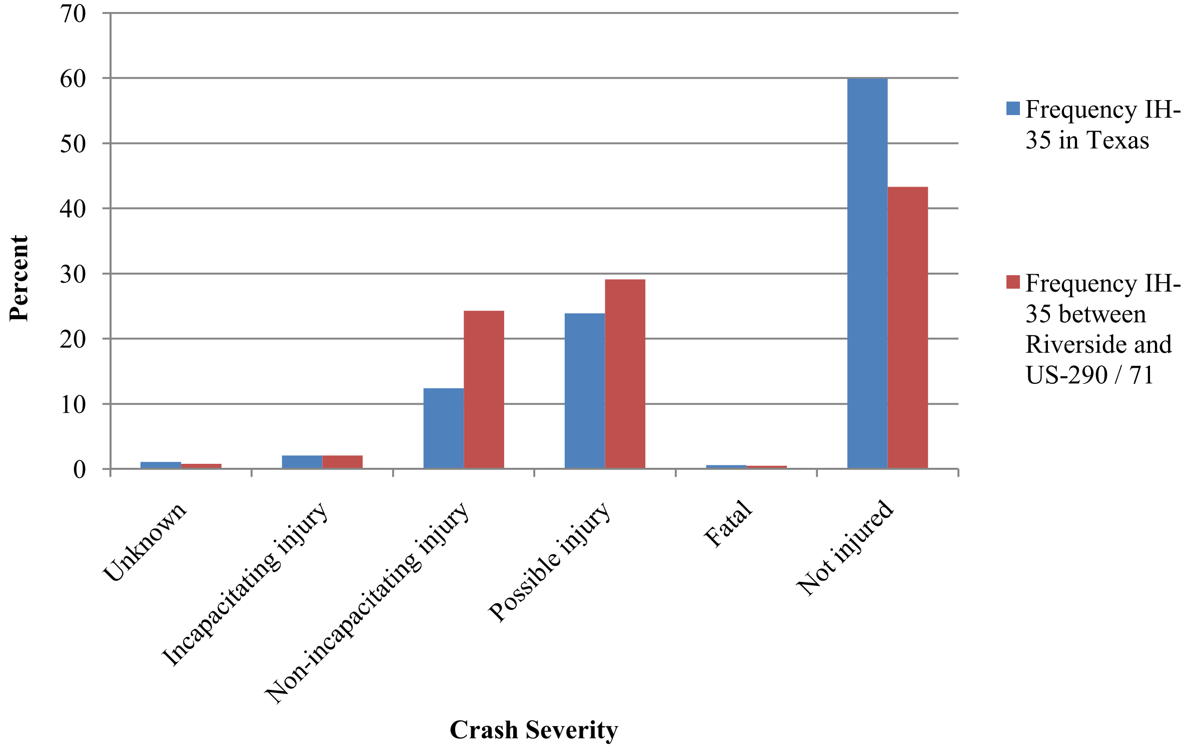


Table 4: Crash Severity

According to the frequency analysis, the majority of crashes on IH-35 both in the state and in the project section in 2009 had no injuries. However, in the IH-35 segment between Riverside and US-290 there is equal or greater percentage of injuries compared to that of the entire IH-35 in Austin. The greatest difference is seen for non-incapacitating injuries, where the percentage is almost two times as much, 24.3 percent locally versus 12.4 percent statewide. At the same time, the percentage of fatalities on the Austin segment is less compared to the state percentage (0.5 to 0.6 percent), but this number is small relative to other injuries sustained during the crashes.

5.5 Collision Type

Different types of collisions occur on highways. The type of collision depends on the highway conditions present. Examples of collisions include a moving car striking a stationary one, a moving car hitting a moving car, a moving car striking an object, amongst others. A collision may be in the opposite direction or same direction. The CRIS identifies nearly 50 different types of collision scenarios.

Type of Collision	Frequency IH-35 in Texas	Percent	Frequency IH-35 between Riverside and US-290 / 71	Percent
Oncoming motor vehicles (all directions)	14701	11.2	140	3.8
Angle	10643	8.1	471	12.7
Straight direction - rear end	36672	27.9	1358	36.6
Straight direction - side swipe	28780	21.9	466	12.6
Straight direction - one stopped	29791	22.7	984	26.5
Straight direction - other	6508	5.0	174	4.7
Opposing direction (all directions)	3950	3.0	54	1.5
Other	388	0.3	60	1.6
Total	131433	100	3707	100.0

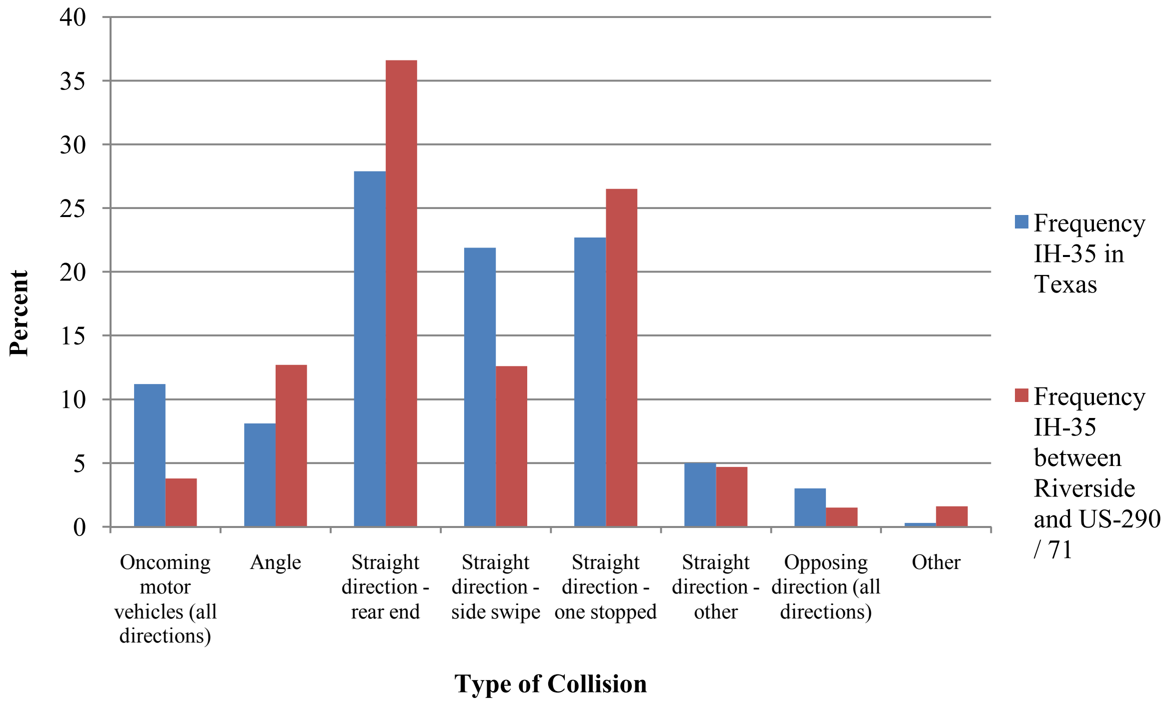


Table 5: Collision Type

Despite the numerous collision types reported, the three most common collision types in both sample groups are rear end collisions, sideswipe (or side car) collisions, and a collision where one vehicle is moving and the other is stopped. On IH-35 throughout all of Texas, these accidents comprise 72.5 percent of all collision types versus 75.7 percent in this highway segment.

Rear end and side car collisions are common crashes that occur in queue scenarios and during congestion periods. In these settings, vehicles speed up and slow down abruptly. An approaching vehicle may not have adequate time or distance to react, and collides with the vehicle in front. If that vehicle is in a queue or is approaching a queue, it may strike another vehicle, causing a chain reaction that increases the numbers of injuries and damages.

5.6 ROAD ALIGNMENT

The road alignment variable refers to the type of roadway geometry where the crash took place. Two main categories exist for the variable: straight or curve; each category is further broken down into whether or not the roadway geometry is level (flat), grade (on a slope), or on a hillcrest. The 2009 CRIS database has nine different types of road alignment configurations, including OTHER, UNKNOWN, and NOT REPORTED. The road alignment variable provides insight into the potential role that highway geometry may play on crash frequency, severity, type of collision, and more.

Road Alignment	Frequency IH-35 in Texas	Percent	Frequency IH-35 between Riverside and US-290 / 71	Percent
Straight, level	100777	76.7	2796	75.4
Straight, grade	15598	11.9	516	13.9
Straight, hillcrest	4644	3.5	66	1.8
Curve, level	4215	3.2	99	2.7
Curve, grade	3441	2.6	59	1.6
Curve, hillcrest	701	.5	20	.5
Other (explain in narrative)	488	.4	1	.0
Unknown	5	.0	0	.0
Not Reported	1564	1.2	150	4.0
Total	131433	100.0	3707	100.0

Table 6: Road Geometry of Crashes

Compared to the rest of IH-35 in Texas, the Austin section has less crashes occurring on curves. A majority of the crashes in both samples occurred on a straight, level surface. It must be noted, however, that even the majority of the 2.2 mile segment between Riverside Drive and US-290 / 71 is straight, and the 0.5 mile horizontal curve only occurs between Riverside and Woodland Avenue. The percentage of crashes with the "not reported" classification is also much more in

Austin compared to the statewide count on IH-35. If a significant number of these actually occurred on a curve, it would be enough to dramatically shift the percentages and distribution. Most importantly, only looking at the road alignment frequencies alone does not provide detail about other variables, such as crash severity including whether injuries were sustained. These variables must be compared with each other to provide a better characterization of the safety situation.

5.7 CROSSTABS

A cross-tabulation analysis is a classification of two variables to display the frequency of the variables across each other. Also known as a contingency table, crosstabs show the frequency of certain traits across a bivariate distribution and may provide insight into a possible relationship or correlation between the two variables. A cross-tabulation was performed for both the entire IH-35 length in Texas, and the section between Riverside Drive and SH-71. The following several sections detail several key crosstabs between two variables to highlight the safety concerns on the Austin segment.

5.7.1 Collision Type versus Crash Severity

Collsn_Type * Crash_Sev_ID Crosstabulation

IH-35 in Texas			Crash_Sev_ID						Total
			UNKNOWN	INCAPACITATING INJURY	NON-INCAPACITATING	POSSIBLE INJURY	FATAL	NOT INJURED	
Collsn_Type	OMV (all directions)	Count	912	816	2170	2393	279	8131	14701
		% within Collsn_Type	6.2%	5.6%	14.8%	16.3%	1.9%	55.3%	100.0%
	ANGLE	Count	39	329	1631	2838	6	5800	10643
		% within Collsn_Type	.4%	3.1%	15.3%	26.7%	.1%	54.5%	100.0%
	SD both going straight (rear end)	Count	77	540	4556	10275	130	21094	36672
		% within Collsn_Type	.2%	1.5%	12.4%	28.0%	.4%	57.5%	100.0%
	SD both going straight (side swipe)	Count	125	538	2934	5275	56	19852	28780
		% within Collsn_Type	.4%	1.9%	10.2%	18.3%	.2%	69.0%	100.0%
	SD one straight - one stopped	Count	156	319	3811	8984	296	16225	29791
		% within Collsn_Type	.5%	1.1%	12.8%	30.2%	1.0%	54.5%	100.0%
	SD OTHER	Count	39	75	436	875	0	5083	6508
		% within Collsn_Type	.6%	1.2%	6.7%	13.4%	.0%	78.1%	100.0%
	OD (all directions)	Count	33	155	648	754	63	2297	3950
		% within Collsn_Type	.8%	3.9%	16.4%	19.1%	1.6%	58.2%	100.0%
	O (include Not Reported)	Count	0	0	57	62	0	269	388
		% within Collsn_Type	.0%	.0%	14.7%	16.0%	.0%	69.3%	100.0%
Total		Count	1381	2772	16243	31456	830	78751	131433
		% within Collsn_Type	1.1%	2.1%	12.4%	23.9%	.6%	59.9%	100.0%

Table 7: Collision Type versus Crash Severity on IH-35 in all of Texas (Crosstabs)

Collsn_Type * Crash_Sev_ID Crosstabulation

IH-35 in Austin between Riverside Drive and US-290 / 71			Crash_Sev_ID						Total
			UNKNOWN	INCAPACITATING INJURY	NON-INCAPACITATING	POSSIBLE INJURY	FATAL	NOT INJURED	
Collsn_Type	OMV (all directions)	Count	5	1	45	16	6	67	140
		% within Collsn_Type	3.6%	.7%	32.1%	11.4%	4.3%	47.9%	100.0%
	ANGLE	Count	0	53	96	177	0	145	471
		% within Collsn_Type	.0%	11.3%	20.4%	37.6%	.0%	30.8%	100.0%
	SD both going straight (rear end)	Count	0	12	323	410	0	613	1358
		% within Collsn_Type	.0%	.9%	23.8%	30.2%	.0%	45.1%	100.0%
	SD both going straight (side swipe)	Count	4	0	87	115	0	260	466
		% within Collsn_Type	.9%	.0%	18.7%	24.7%	.0%	55.8%	100.0%
	SD one straight - one stopped	Count	16	12	312	249	12	383	984
		% within Collsn_Type	1.6%	1.2%	31.7%	25.3%	1.2%	38.9%	100.0%
	SD OTHER	Count	4	0	12	44	0	114	174
		% within Collsn_Type	2.3%	.0%	6.9%	25.3%	.0%	65.5%	100.0%
	OD (all directions)	Count	0	0	16	16	0	22	54
		% within Collsn_Type	.0%	.0%	29.6%	29.6%	.0%	40.7%	100.0%
	O (include Not Reported)	Count	0	0	10	50	0	0	60
		% within Collsn_Type	.0%	.0%	16.7%	83.3%	.0%	.0%	100.0%
Total		Count	29	78	901	1077	18	1604	3707
		% within Collsn_Type	.8%	2.1%	24.3%	29.1%	.5%	43.3%	100.0%

Table 8: Collision Type versus Crash Severity on the IH-35 Section in Austin (Crosstabs)

Here the collision variable is crosstabbed with the crash severity variable to see the extent of the damages associated with different collision types. The main interest in this crosstabs analysis is identifying the crash severity associated with rear end (both vehicles moving and one car stopped) and sidecar collisions. For rear end collisions with both vehicles moving considering all of IH-35 in Texas, 12.4 percent produced a non-incapacitating injury, 28 percent produced a possible injury, and 57.5 percent of the crashes had no injuries reported; meanwhile in the Austin segment, these numbers are 23.8 percent, 30.2 percent, and 45.1 percent, respectively. For sidecar collisions along IH-35 in Texas, 10.2 percent of the crashes had non-incapacitating injury, 18.3 percent possible injury, and 69.0 percent had no reported injuries; for the Austin segment, this is 18.7 percent, 24.7 percent, and 55.8 percent, respectively. Finally for rear end collisions where one car is moving and the other is not, along IH-35 in Texas these numbers are 12.8 percent, 30.2 percent, and 54.5 percent; in Austin, this is 31.7 percent, 25.3 percent, and 38.9 percent respectively.

For rear end and sidecar collisions in both the Austin segment and IH-35 throughout the entire state, there is a higher percentage of injuries sustained from such crashes compared to other types of collisions. Recall that in Austin, rear end (moving and one not moving) and side car collisions constitute 36.6 percent, 12.6 percent, and 26.5 percent, respectively. These percentages are higher than the state average on IH-35. For the Austin segment, the high number of rear end and sidecar collisions, and the frequent injuries sustained make queue safety an important issue in this area.

5.7.2 Road Alignment versus Collision Type

This section examines the relationship between the road alignment and the type of collision that occurred. During peak periods, IH-35 through downtown Austin is very congested with passenger cars and container trucks. The Riverside curve occurs just before the main downtown area while headed northbound, and this area becomes congested regularly. Rear end and side car collisions are the most common type of collisions during congested periods on highway facilities. They can be caused by a vehicle failing to notice the car ahead and stop in time. In the case of special road alignments, the vehicle may have additional difficulty seeing downstream queues.

Road_Algn_ID * Collsn_Type Crosstabulation

IH-35 in Texas			Collsn_Type								Total
			OMV (all directions)	ANGLE	SD both going straight (rear end)	SD both going straight (side swipe)	SD one straight – one stopped	SD OTHER	OD (all directions)	O (include Not Reported)	
Road_Algn_ID	STRAIGHT, LEVEL	Count	10365	9386	27773	22281	22015	5340	3324	293	100777
		% within Road_Algn_ID	10.3%	9.3%	27.6%	22.1%	21.8%	5.3%	3.3%	.3%	100.0%
	STRAIGHT, GRADE	Count	1794	699	4947	3661	3774	377	334	12	15598
		% within Road_Algn_ID	11.5%	4.5%	31.7%	23.5%	24.2%	2.4%	2.1%	.1%	100.0%
	STRAIGHT, HILLCREST	Count	403	202	1572	625	1673	115	50	4	4644
		% within Road_Algn_ID	8.7%	4.3%	33.9%	13.5%	36.0%	2.5%	1.1%	.1%	100.0%
	CURVE, LEVEL	Count	821	128	774	847	1056	463	126	0	4215
		% within Road_Algn_ID	19.5%	3.0%	18.4%	20.1%	25.1%	11.0%	3.0%	.0%	100.0%
	CURVE, GRADE	Count	733	86	824	847	758	148	44	1	3441
		% within Road_Algn_ID	21.3%	2.5%	23.9%	24.6%	22.0%	4.3%	1.3%	.0%	100.0%
	CURVE, HILLCREST	Count	139	10	198	240	76	0	38	0	701
		% within Road_Algn_ID	19.8%	1.4%	28.2%	34.2%	10.8%	.0%	5.4%	.0%	100.0%
	OTHER	Count	191	18	82	42	129	4	4	18	488
		% within Road_Algn_ID	39.1%	3.7%	16.8%	8.6%	26.4%	.8%	.8%	3.7%	100.0%
	UNKNOWN	Count	1	0	4	0	0	0	0	0	5
		% within Road_Algn_ID	20.0%	.0%	80.0%	.0%	.0%	.0%	.0%	.0%	100.0%
	NOT REPORTED	Count	254	114	498	237	310	61	30	60	1564
		% within Road_Algn_ID	16.2%	7.3%	31.8%	15.2%	19.8%	3.9%	1.9%	3.8%	100.0%
Total		Count	14701	10643	36672	28780	29791	6508	3950	388	131433
		% within Road_Algn_ID	11.2%	8.1%	27.9%	21.9%	22.7%	5.0%	3.0%	.3%	100.0%

Table 9: Road Alignment versus Collision Type on IH-35 in Texas (Crosstabs)

Road_Algn_ID * Collsn_Type Crosstabulation

IH-35 in Austin between Riverside Drive and US-290 / 71			Collsn_Type: OMV (all directions)	ANGLE	SD both going straight (rear end)	SD both going straight (side swipe)	SD one straight - one stopped	SD OTHER	OD (all directions)	O (include Not Reported)	Total
Road_Algn_ID	STRAIGHT, LEVEL	Count	95	435	1028	397	674	115	42	10	2796
		% within Road_Algn_ID	3.4%	15.6%	36.8%	14.2%	24.1%	4.1%	1.5%	.4%	100.0%
	STRAIGHT, GRADE	Count	18	16	252	42	166	10	12	0	516
		% within Road_Algn_ID	3.5%	3.1%	48.8%	8.1%	32.2%	1.9%	2.3%	.0%	100.0%
	STRAIGHT, HILLCREST	Count	5	6	40	0	15	0	0	0	66
		% within Road_Algn_ID	7.6%	9.1%	60.6%	.0%	22.7%	.0%	.0%	.0%	100.0%
	CURVE, LEVEL	Count	6	0	14	0	40	39	0	0	99
		% within Road_Algn_ID	6.1%	.0%	14.1%	.0%	40.4%	39.4%	.0%	.0%	100.0%
	CURVE, GRADE	Count	10	0	4	12	29	4	0	0	59
		% within Road_Algn_ID	16.9%	.0%	6.8%	20.3%	49.2%	6.8%	.0%	.0%	100.0%
	CURVE, HILLCREST	Count	4	0	0	0	16	0	0	0	20
		% within Road_Algn_ID	20.0%	.0%	.0%	.0%	80.0%	.0%	.0%	.0%	100.0%
	OTHER	Count	1	0	0	0	0	0	0	0	1
		% within Road_Algn_ID	100.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%
	NOT REPORTED	Count	1	14	20	15	44	6	0	50	150
		% within Road_Algn_ID	.7%	9.3%	13.3%	10.0%	29.3%	4.0%	.0%	33.3%	100.0%
Total		Count	140	471	1358	466	984	174	54	60	3707
		% within Road_Algn_ID	3.8%	12.7%	36.6%	12.6%	26.5%	4.7%	1.5%	1.6%	100.0%

Table 10: Road Alignment versus Collision Type on the IH-35 section in Austin (Crosstabs)

There are some significant differences in the crosstabs between IH-35 statewide and in the study section. Not surprisingly, rear end (both types) and side car collisions are the most common collision types in each road alignment category. These collisions make up a higher percentage of collisions in the Austin segment for most of the roadway alignment categories as compared to the rest of the state. Numerous reasons can be suggested for this and these may include the formations of queues from the congestion or roadway geometry. At the same time, in the Austin segment, the majority of the collision types on curves (level, grade, and hillcrest) are rear end collisions where only one of the cars is moving. This crosstabulation primarily looks at the frequency distribution of collision types across different road alignments, and does not provide any information regarding correlation between the two variables. A more in depth look involving changes in grade and curve radius may provide further insight into the role of curves in vehicle collisions.

5.7.3 Road Alignment versus Crash Severity

This crosstab looks at the distribution of crash severity over different road alignment types. The majority of highway crashes on IH-35 occur on roads that are straight and level (flat); this is true both throughout the state and in the Austin region. However, for the crashes that do occur on curves the crash severity is greater for some key injury categories. The Austin segment has a large horizontal curve that may play a role in the statistics.

IH-35 in Texas			Crash Severity						
			Unknown	Incapacitating Injury	Non-incapacitating	Possible Injury	Fatal	Not injured	Total
Road Alignment	Straight, level	Count	948	1911	11779	24009	723	61407	100777
		% within Road Alignment	.9%	1.9%	11.7%	23.8%	.7%	60.9%	100.0%
	Straight, grade	Count	104	406	2340	4374	63	8311	15598
		% within Road Alignment	.7%	2.6%	15.0%	28.0%	.4%	53.3%	100.0%
	Straight, hillcrest	Count	37	145	850	1076	2	2534	4644
		% within Road Alignment	.8%	3.1%	18.3%	23.2%	.0%	54.6%	100.0%
	Curve, level	Count	54	85	443	759	27	2847	4215
		% within Road Alignment	1.3%	2.0%	10.5%	18.0%	.6%	67.5%	100.0%
	Curve, grade	Count	22	157	463	737	15	2047	3441
		% within Road Alignment	.6%	4.6%	13.5%	21.4%	.4%	59.5%	100.0%
	Curve, hillcrest	Count	21	37	94	91	0	458	701
		% within Road Alignment	3.0%	5.3%	13.4%	13.0%	.0%	65.3%	100.0%
	Other (explain in narrative)	Count	77	0	13	31	0	367	488
		% within Road Alignment	15.8%	.0%	2.7%	6.4%	.0%	75.2%	100.0%
	Unknown	Count	0	0	0	0	0	5	5
		% within Road Alignment	.0%	.0%	.0%	.0%	.0%	100.0%	100.0%
	Not reported	Count	118	31	261	379	0	775	1564
		% within Road Alignment	7.5%	2.0%	16.7%	24.2%	.0%	49.6%	100.0%
Total		Count	1381	2772	16243	31456	830	78751	131433
		% within Road Alignment	1.1%	2.1%	12.4%	23.9%	.6%	59.9%	100.0%

Table 11: Road Alignment versus Crash Severity on IH-35 in Texas (Crosstabs)

IH-35 in Austin between Riverside Drive and US-290 / 71			Crash Severity						Total
			Unknown	Incapacitating Injury	Non-incapacitating	Possible Injury	Fatal	Not injured	
Road Alignment	Straight, level	Count	10	59	600	896	12	1219	2796
		% within Road Alignment	.4%	2.1%	21.5%	32.0%	.4%	43.6%	100.0%
	Straight, grade	Count	2	13	252	46	0	203	516
		% within Road Alignment	.4%	2.5%	48.8%	8.9%	.0%	39.3%	100.0%
	Straight, hillcrest	Count	0	0	6	13	0	47	66
		% within Road Alignment	.0%	.0%	9.1%	19.7%	.0%	71.2%	100.0%
	Curve, level	Count	0	6	0	38	1	54	99
		% within Road Alignment	.0%	6.1%	.0%	38.4%	1.0%	54.5%	100.0%
	Curve, grade	Count	1	0	21	0	5	32	59
		% within Road Alignment	1.7%	.0%	35.6%	.0%	8.5%	54.2%	100.0%
	Curve, hillcrest	Count	16	0	0	0	0	4	20
		% within Road Alignment	80.0%	.0%	.0%	.0%	.0%	20.0%	100.0%
	Other (explain in narrative)	Count	0	0	1	0	0	0	1
		% within Road Alignment	.0%	.0%	100.0%	.0%	.0%	.0%	100.0%
	Not reported	Count	0	0	21	84	0	45	150
		% within Road Alignment	.0%	.0%	14.0%	56.0%	.0%	30.0%	100.0%
Total		Count	29	29	78	901	1077	18	1604
		% within Road Alignment	100.0%	.8%	2.1%	24.3%	29.1%	.5%	43.3%

Table 12: Road Alignment versus Crash Severity on the IH-35 Section in Austin (Crosstabs)

In the Austin section, a high percentage of accidents that occur on a grade have non-incapacitating injuries. For accidents that occur on a straight roadway grade, 48.8 percent have non-incapacitating injuries. Meanwhile, for the 59 crashes occurring on a curved roadway grade, 21 (35.6 percent) of these are non-incapacitating injuries, and 5 are even fatal (8.5 percent). The fatal percentage of the crashes that occur in a curve-grade area in the Austin segment is much higher than the statewide average for IH-35, which is at 0.4%. Additionally, the percentage of fatalities in crashes that occur on a curve-level area in the Austin segment is also 6.1 percent (6 out of 99 crashes). This can be compared with 2.0 percent for incapacitating injuries in the same category statewide (85 out of 4215).

5.8 SIGNIFICANCE TESTING

In addition to the frequency analysis and crosstabulation of several key variables from the TXDOT CRIS database, significance testing is also important to demonstrate the high accident rate in the Austin segment. Significance testing was performed to compare the accident rates on IH-35 in Austin between SH-71 and Riverside Drive and IH-35 throughout the entire state of Texas. The objective of this testing is to show that the particular section of IH-35 in Austin has a significantly higher accident rate as compared to the rest of the state.

The significance test used was a paired sample t test that compared the accident rates between the two variables. The data used is the same data gathered from TXDOT's Crash Records Information System database. All the crashes were classified by the month they took place, and then divided by the number of centerline miles in their respective segment (2.5 for the Riverside segment, and 407.2 miles as gathered from Google maps and TXDOT, respectively). This was done to standardize the figures and provide a relative number of accidents per mile for each month. The two datasets can be seen below:

Month	IH-35 in Texas (raw)	IH-35 in Texas (relative), per mile	IH-35 Austin section (raw)	IH-35 Austin section (relative), per mile
1	9471	23.26	312	124.80
2	9676	23.76	355	142.00
3	11829	29.05	419	167.60
4	11020	27.06	231	92.40
5	10808	26.54	346	138.40
6	10699	26.27	332	132.80
7	11607	28.50	287	114.80
8	10658	26.17	262	104.80
9	9831	24.14	255	102.00
10	12560	30.85	261	104.40
11	11666	28.65	460	184.00
12	11608	28.51	187	74.80

**There are 407.195 centerline miles of IH-35 in Texas, and 2.5 miles in the Riverside curve.*

Table 13: Accident Rates per Month.

The relative variables were compared in a two tailed t-test in SPSS in the 95 percent confidence interval. The paired-test yielded the following results:

Paired Samples Statistics

	Mean	N	Std. Deviation	Std. Error Mean
IH35_Texas_relative	26.8967	12	2.34038	.67561
IH35_Austin_relative	123.5667	12	31.40467	9.06575

Paired Samples Correlations

	N	Correlation	Sig.
IH35_Texas_relative & IH35_Austin_relative	12	.033	.918

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
IH35_Texas_relative - IH35_Austin_relative	-96.67000	31.41403	9.06845	-116.62952	-76.71048	-10.660	11	.000

Table 14: Paired T-Test Results at 95% Confidence.

From the results, it can be seen that the t-value is -10.660. This is compared to a t-value of -2.201 at two sided 95 percent confidence and 11 degrees of freedom. Since the t-value is greater than the t-statistic, this means that at the 95 percent confidence interval there is a significant difference between the two pairs of accident rates. The number of accidents in the Austin segment is statistically significant compared to the number of accidents on all of IH-35 throughout Texas.

5.9 SUMMARY

This section provides several key findings from the 2009 Crash Records Information System database. The purpose of these findings is to demonstrate differences between the Austin IH-35 segment and IH-35 in the rest of the state. These findings aim to show the unique characteristics and needs of this highway segment to warrant the design of a queue warning system.

From these results, it can be seen that crashes in the Austin section have more injuries (especially non-incapacitating injuries). There are also more rear end collisions. The stretch of IH-35 between US-290 / 71 and Riverside Drive has the most accidents on IH-35 in Austin. The curve geometry of the region is associated with a higher number of fatalities and incapacitating injuries relative to the rest of IH-35 in the state. Numerous safety concerns can be seen from the queue behavior and highway geometry of the section. The next chapter deals with the design of a queue warning system for this highway section to address these concerns.

Chapter 6: Queue Warning System

6.1 Queue Warning System Design

In the FHWA's *Active Traffic Management: the Next Step in Congestion Management*, the task force identified a series of guidelines and recommendations for the design of a queue warning system. These recommendations include:

- Deployment in conjunction with speed harmonization.
- Sufficient sensor deployment for traffic monitoring to support the strategy.
- Adequate installation of sign gantries to ensure that at least one queue warning sign is in sight at all times.
- An expert system that deploys the strategy based on prevailing roadway conditions without requiring operator intervention. It is critical that this expert system be reliable and accurate to gain the trust and acceptance of the public.
- Uniform signing to indicate congestion ahead.
- Connection to a traffic management center that serves as the focal point for the system (Mirshahi, 2007).

This section is focused on the development of a proposed queue warning system to address the operations and safety needs of a freeway segment similar to Interstate 35 between Riverside Drive and St. Elmo Road. As mentioned in a previous chapter, this segment of IH-35 features geometric constraints, daily recurring congestion, and incident related congestion. While the ATM task force recommends the use of a queue warning system in conjunction with speed harmonization (variable speed limits), the scope of this paper is centered on developing an extensive queue warning system and its potential for both safety and operations concerns.

This chapter is divided into five parts for the queue warning system design. First, the field equipment is discussed, with descriptions of the various technologies available and currently in use. Then, the queue detection algorithm is investigated, detailing how the gathered traffic data is processed and analyzed to determine the appropriate solution. The graphical user interface is mentioned next, identifying the relevant information needed for information dissemination. Information dissemination using the dynamic message sign is discussed for the message selection and control. Finally, the performance measures detail methods for evaluating the system and performance evaluation.

The Texas Transportation Institute (Wiles, 2002) recommends different queue warning system strategies for the different scenarios that are encountered on the roadway. The four major types of scenarios include: geometric constraints, congestion related to recurrent traffic conditions, congestion related to work zones, and congestion related to incidents. The type of scenario is critical for the design of a control scheme to determine the message to be disseminated for roadway information.

6.2 Field Equipment

6.2.1 Sensor Systems

Detection equipment and sensor systems are critical to gathering the field information and raw traffic data that is critical to identify the real time traffic conditions for a real time management system. Detection equipment can be classified as two types: invasive and noninvasive. They can serve a number of functions, including measuring traffic flow and environmental conditions, disseminating traveler information, monitoring and evaluating system performance, and serving other operations functions such as incident detection and transportation planning (USDOT, 2006). Numerous types of detection equipment exist, but the most common are inductive loops, radar detection, and video; other types include infrared, ultrasonic, and optical sensors.

The inductive loop is the most commonplace traffic detection technology currently in practice. Introduced in the 1960s, an inductance loop consists of insulated wire configured in a loop placed several inches below the pavement surface in a sawcut. The wire extends to a pull box, which is in turn connected to an electronics unit in a roadside controller cabinet. The inductive loop works by detecting the change in inductance created by a vehicle entering or leaving the loop. The loop typically ranges from 5 to 6 feet in width, and is placed in the middle of the lane (Mimbela et. al, 2007).

Inductive loops can provide data regarding vehicle count, occupancy, presence, and passage. Speed, another important highway parameter, can also be inferred using two loop detectors at a specified distance apart, or a single loop and an algorithm that considers the length and the passing time of the vehicle. The advantages of inductance loops include their ability to gather basic traffic data, insensitivity to inclement weather such as fog and snow, and the large potential applications in different operations, as well as its low cost and flexible design. Inductive loops are considered to be a mature traffic detection technology (USDOT, 2006). At the same time, the disadvantages and shortcomings of inductive loops are well known and noted. Inductive loops require lane closures and pavement cuts for installation or repairs, temporarily increasing delay on the affected roadway that are often costly. Inductance loop detectors can only gather traffic data for a single lane, rather than multiple lane detection. They are commonly used at signalized intersections to sense approaching vehicles enabling the signal controller to respond to real time traffic demand. Loops are also used on highways to count number of passing cars during specific time periods.

Radar is another type of traffic detection used on roadway facilities. Radar technology uses electromagnetic waves at the radio frequency to determine vehicle speed and presence on a particular roadway segment. An antenna emits high frequency radio waves at regular intervals. The waves move outward and reflect as they hit a surface or vehicle, in this case. A receiver picks up the reflected wave, and this in turn allows the device to calculate the presence of the vehicle. To calculate the speed of an object, radar technology uses Doppler shift.

Doppler shift refers to detecting changes in radio wave frequency to calculate the moving speed of a vehicle. Here, the antenna emits a constant, high energy frequency signal which hits the object at increasing distances. The waves hit the vehicle and reflect, and the signal picks up this first response. Meanwhile, subsequent waves hit the vehicle, and the radar device notes the change in frequency to calculate the speed. A Doppler radar can only detect moving vehicles, and records vehicle counts and speeds (USDOT, 2006). The most common radar system for traffic detection is microwave radar using Doppler technology. Applications for radar detection technology include monitoring traffic queues, classifying vehicles, and providing real time data for dynamic traffic signal systems (USDOT, 2006).

Video image technology is based on the use of cameras to detect the presence of vehicles. A video detection system typically consists of one or more video cameras mounted over the lane at the intersection. The camera is connected to a microprocessor to digitize and process the images, which in turn gets converted into traffic data with the help of software. The system "detects" vehicles by segmenting the image observing color changes between black and white in successive frames, with algorithm discrepancies to disregard shades of gray that may be caused by limited visibility, weather, or shadows (T.T.I., 2002). Specific features are then extracted from the image, which then in turn are classified and tracked for data extraction. Different tracking approaches include blob or region, active contour, model based, feature based, color based, and pattern based (U.S. DOT, 2006).

Unlike inductive loops, a video detection system requires no lane closures or pavement cuts for installation, and can track vehicles across multiple lanes for statistics such as speed, flow rate, occupancy, and vehicle presence (Mimbela et. al, 2007). Shortcomings for video detection systems include reliability concerns in limited visibility (weather, night), and the relative young age of the technology (pilot programs began in the 1970s and 80s). Video detection systems are mainly used at intersections to detect approaching traffic, although they may also be used on highway facilities for incident management and travel information dissemination. There is ongoing research to broaden the use of vehicle detection systems on highway facilities, namely for accurate vehicle counts.

Type	Traffic Information Gathered	Advantages	Disadvantages
Inductive Loops	• Vehicle counts • Vehicle presence • Occupancy	• Low cost • Mature technology • High accuracy • Flexible design	• Invasive; installation and maintenance requires lane closure • Can fail with poor road conditions, temperature, stress
Radar (microwave)	• Speed	• Does not require lane closures • Can record over multiple lanes • Not susceptible to weather	• Only detects moving vehicles • Not accurate as vehicle counters in intersections
Video	• Vehicle counts • Speed • Occupancy	• Does not require lane closures • Can record over multiple lanes • May have high accuracy	• Weather, situations of limited visibility may hinder accuracy

Table 15: Summary of Common Traffic Detection Technology

Selecting an appropriate traffic detection technology requires a careful evaluation of the desired data uses and its role in the queue warning system. For this Interstate 35 highway segment between the Colorado River and St. Elmo Road, the video detection technology is recommended. This is largely because of video's ability to record traffic across multiple lanes, as well as its relative ease in installation. Inductive loops are not an option because the lane closures and pavement cuts required for installation would have significant traffic and economic impacts on IH-35, a major north-south highway corridor in the United States. Meanwhile, radar is also discouraged because it primarily observes moving vehicles, whereas traffic on IH-35 may be stationary and non-uniform. Video detection will be able to provide counts on vehicle speed and occupancy, as well as incident detection for the Austin traffic management center. Of course, visibility concerns regarding video detection accuracy must be addressed to demonstrate that traffic counts are within a minimum level of acceptance.

The placement of each detector unit is largely based on the roadway geometry characteristics. Units must be properly spaced and located before or after freeway entrances and exits at key cross streets to account for changing flow levels. Additionally, horizontal and vertical sight distances must be considered for effective traffic monitoring and detection. Video cameras are typically elevated on poles, and the detection area should be as free of sight obstructions as possible. Sight obstructions include shadows, sharp curvature, and underpasses. A rough placement for 8 video camera detectors is proposed below and includes roughly 500 meters (1640 feet) spacing. Ideally the video cameras would be placed atop existing overhead structures on IH-35, as many camera brands require a minimum height for calibration. The video cameras would be largely responsible for traffic detection on the main lanes.

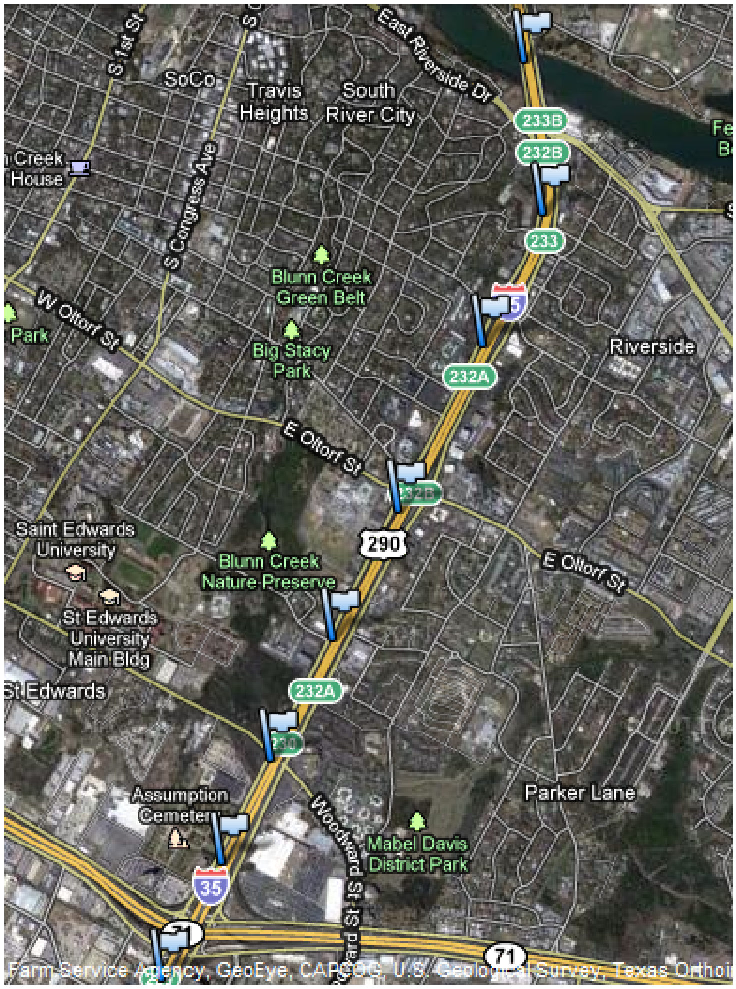


Figure 15: Proposed Video Detector Placement on IH-35 Corridor
(Source: Google Maps).

6.2.2 Signing Systems

Another important component in a queue warning system is the signage required to notify approaching vehicles. Signing is used to notify motorists of the queue warning system and the presence of queues or notable highway geometry. Here signing refers to fixed messages and is separate from dynamic message signs in which the message may change according to the traffic conditions. The dimensions and physical properties for signing can be found in the *Manual on Uniform Traffic Control Devices*. In the *MUTCD*, warning signs are classified according to categories (Roadway, Traffic, or Other), and further organized into groups. Each group has its own section and sign designations with sizes specifications for different roadway types. Several signs are described below; for a complete list consult the *MUTCD* Table 2C-1 (FHWA 2009).

Category	Group	Signs or Plaques
Roadway Related	Changes in Horizontal Alignment	Turn, Curve, Reverse Turn, Reverse Curve, Winding Road, Hairspin Curve, 270-Degree Curve
		Advisory Speed
		Large Arrow (one direction)
	Vertical Alignment	Hill
		Hill Blocks View
Traffic Related	Advance Traffic Control	Stop Ahead, Yield Ahead, Signal Ahead, Be Prepared To Stop, Speed Reduction, Drawbridge Ahead, Ramp Meter Ahead
	Traffic Flow	Merge, No Merge Area, Lane Ends, Added Lane, Two-Way Traffic, Right Lane Exit Only Ahead, No Passing Zone
Other Supplemental Plaques	Photo Enforced	Photo Enforced

Table 16: Example Categories of Warning Signs and Plaques in the *MUTCD* (MUTCD).

One sign that may be used is a queue warning sign that notifies motorists of a downstream queue. This warning may be in the form of an image or text. Several countries in Europe and New Zealand use an image of three vehicles together along with a written warning of queues over the next several miles. In a 2005 report on the design of queue warning systems, the Texas Transportation Institute recommended the following image adapted from the international versions. These signs should be placed upstream at a minimum distance of several miles of the main congested area. If the sign also contains text detailing the length of the congested segment, the sign must be placed even further back. This may allow the motorist to reroute or at the very least be aware of an abrupt change in speed ahead.

Figure 16: Examples of International Queue Warning Signs.
(Clockwise from top left) Turkey, New Zealand, England
(Source: Wiles et. al).

Figure 17: TTI Conceptual Design for a Proposed Queue Warning Sign (Source: Wiles et. al).

The signs can be used independently or in conjunction with dynamic message signs as part of the queue warning system. The message selection for the sign interface will be discussed in a further section.

For the proposed queue warning system, the queue warning sign should be placed adjacent to the roadway at two points on the IH-35 segment. One sign should be placed several miles before St. Elmo Road where congestion typically forms, while the other should be located a mile before the sharp horizontal curve at Riverside Drive. A possible location for this sign could be on the right column of the overhead sign structure just north of Woodland Avenue. On this overhead, there is already a fixed sign warning of the sharp horizontal curve.

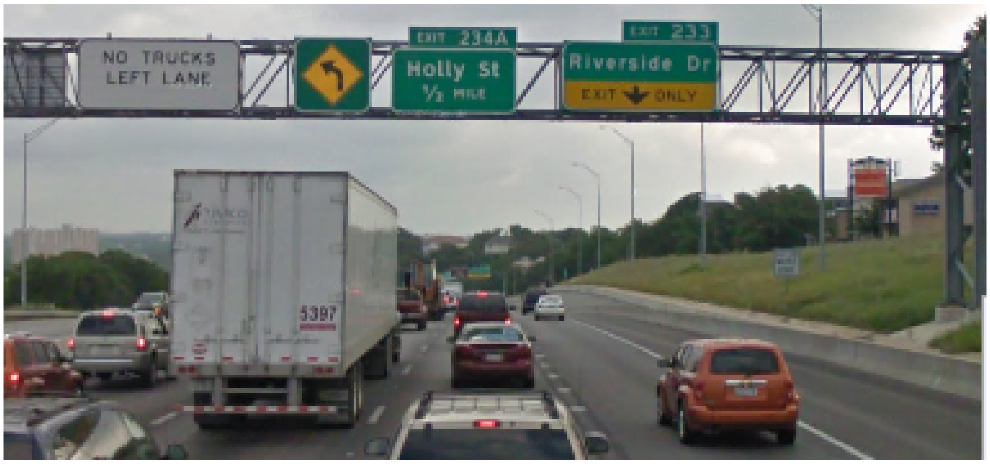


Figure 18: Overhead Structure on IH-35 near Woodland Avenue. Notice Yellow Warning Sign for the Approaching Horizontal Curve (Source: google maps).

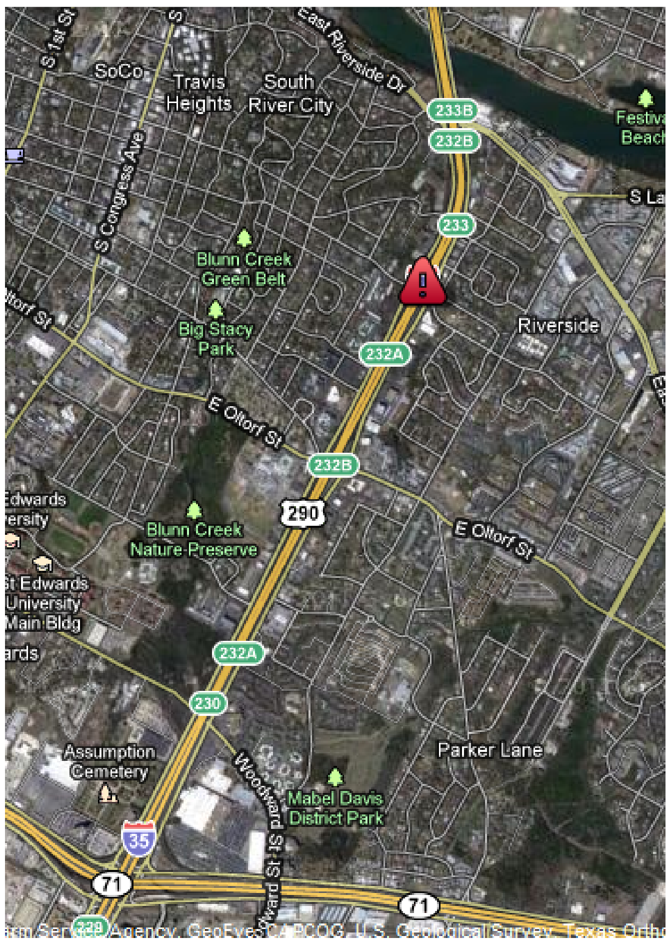


Figure 19: Location of Proposed Queue Warning Sign, near Overhang at Woodland Ave (Source: google maps).

6.3 QUEUE DETECTION ALGORITHM

Once motorists are notified of an approaching queue and the detection systems gather the appropriate site conditions, the information can be relayed to the traffic management center for a queue algorithm to determine the appropriate output. The queue detection algorithm can be separated into four different steps: detection, process, output, and verification. Numerous factors affect the algorithm process and the output message. These factors include the type of queue, time of day, enforcement, and updating process to name a few.

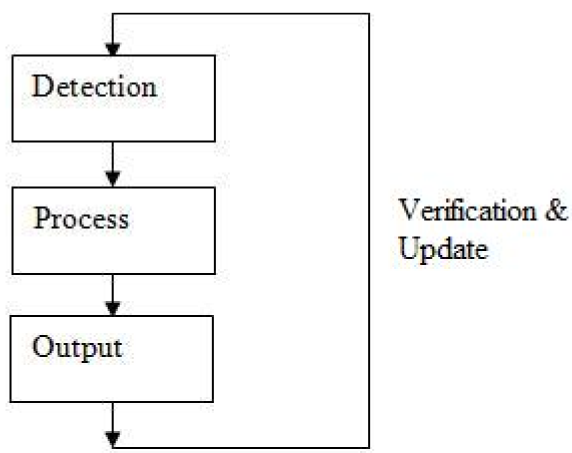


Figure 20: Overview of Queue Warning Algorithm

In the detection step, traffic detection systems identify the real time traffic counts and convert the raw data into information bits that in turn get sent to the traffic management center for identification and processing. As mentioned earlier, video cameras were chosen for the proposed queue warning system on the IH-35 segments due to their noninvasive nature and ability to monitor multiple lanes. Each video camera would record and detect vehicle presence on a specified area by noticing color changes in successive frames. Microprocessors installed in each video camera would digitize the recorded frames and identify the color changes as the moving vehicle. From there, the video camera would determine using the stop gap between each frame to identify the vehicle speed and the number of vehicles present. This digitized information is then transmitted to the Austin traffic management center to be entered into the queue warning algorithm.

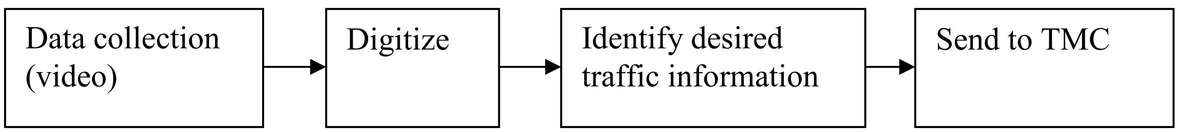


Figure 21: Flow Path for Detection

At the traffic management center, the information is processed through the queue algorithm to generate an output for information dissemination. First, the current average speed of the vehicles is calculated from the information provided by the detection equipment. The speed is then evaluated to see if it is greater or less than a preset threshold. If the speed falls below the set level, then the queue warning system is activated. With the activated queue warning system, vehicle speeds from the detection equipment are referenced to determine the start, end, and length of the queue. Finally, this information is used to determine the appropriate message for output.

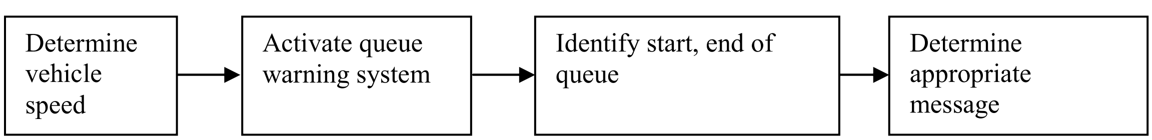


Figure 22: Flow Path for Queue Warning Strategy

The output step is primarily focused on identifying the type of message needed for information dissemination. The first step of determining the appropriate message is to identify the type of queue on the roadway. There are three main types of queues: recurring traffic congestion, work zones, and incident delay. If a dynamic message sign is utilized as part of the queue warning system, then the type of queue present may play a role in choosing the appropriate message, as certain incidents or events may have precedence over others in terms of message formulation. Identifying the type of queue will most likely require human confirmation. After the queue is identified, then an appropriate message can be selected and disseminated. The entire system is continually monitored at the traffic management center, and the video detection system continues to update the traffic conditions as the queue warning system is deployed. The next section of this chapter deals with configuring the message and graphical user interface to suit the queues on the highway segment

.

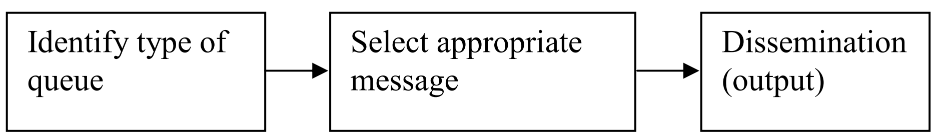


Figure 23: Flow Path for Output

6.4 Graphical User Interface

The design of the graphical user interface is centered on identifying and selecting the appropriate queue message to be displayed to motorists. Several types of GUIs exist, including variable message signs (permanent), temporary and portable variable message signs, and enhanced static signs. The Texas Transportation Institute has published reports on both DMS design and message selection for a queue warning system.

One type of possible GUI to display a queue warning message is the dynamic message sign. DMS vary in their ability to carry text and LED images. They are typically mounted on an overhead structure or are independently set on a cantilever mount. While some DMS may have LED features to allow graphics and images to display, the majority of them contain three lines and approximately 18 characters per line. This is the case for the DMS in Austin. The next section provides a more detailed look into the design of a variable message sign, looking at text capability, and the hierarchy of messages.

Another option for GUI display is the deployment of portable DMS's. In Austin, portable DMS are used in construction, maintenance, and special events, not incident support. The Austin traffic management center is not involved with portable DMS, and neither controls nor designs the messages on the DMS. However, Fort Worth, Houston, and San Antonio all use portable DMS for incident support, and the San Antonio TMC both controls and designs the messages on the portable DMS (Finley, 2001). A typical portable DMS display consists of 3 lines with 18 characters each. If used for queue warning and congestion alerts, portable DMS fixtures may have messages such as:

- CONGESTION AHEAD
- BEWARE OF REAR-END COLLISION
- CONGESTION – CAUTION
- QUEUE AHEAD
- SLOW DOWN
- SLOW TRAFFIC AHEAD PREPARE TO STOP (Wiles et. al., 2002).

The message selection and protocol for portable DMS may be adapted from that of regular DMS, which is detailed in the next section. Portable DMS differs from regular

DMS in that the message is programmed and entered directly on the portable DMS rather than from the traffic management center. An internet search of different portable DMS models show a number of models available including signs with LED display, solar power, and trailer options. Advantages of portable DMS include a cheaper capital price and no installation cost. Disadvantages include less space to convey messages and the absence of direct connection to a TMC for dynamic customization. An operator must come out to program a message and determine when it should be displayed.

Figure 24: Examples of Different Portable DMS
(Source from top left: Iowa DOT, AESYS, FHWA).

Another type of GUI is the use of enhanced static signs. In this case, the signs contain one or two messages about queue warning adorned with lights. The lights are activated and flashed when roadway conditions present a queue. The signs may be placed on an overhead structure along with other signs, or on the side of the road. Messages on the static signs may include the following:

- PREPARE TO STOP WHEN FLASHING
- CONGESTION AHEAD – NEXT TWO MILES [the TWO is fixed]
- TRAFFIC CONGESTION AHEAD – WHEN FLASHING (Wiles et. al, 2002).

A trial queue warning system was deployed in Houston on IH-610 and US-59 in which static signs were placed along the roadside and on overhead structures. The signs had flashing lights that were activated when the video detection systems and the Houston traffic management center deemed the roadways congested. Advantages of enhanced static signs include low cost (capital and maintenance); disadvantages of these signs are the limited message display.

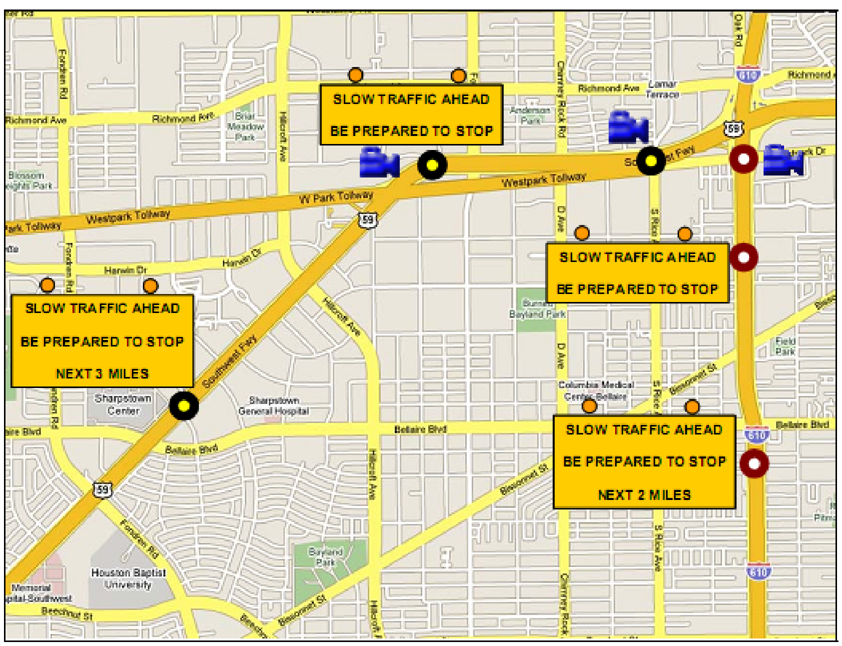


Figure 25: Queue Warning Signs and Their Location, along with Detection Equipment, on IH-610 and US-59 in Houston (Source: Pesti et. al).

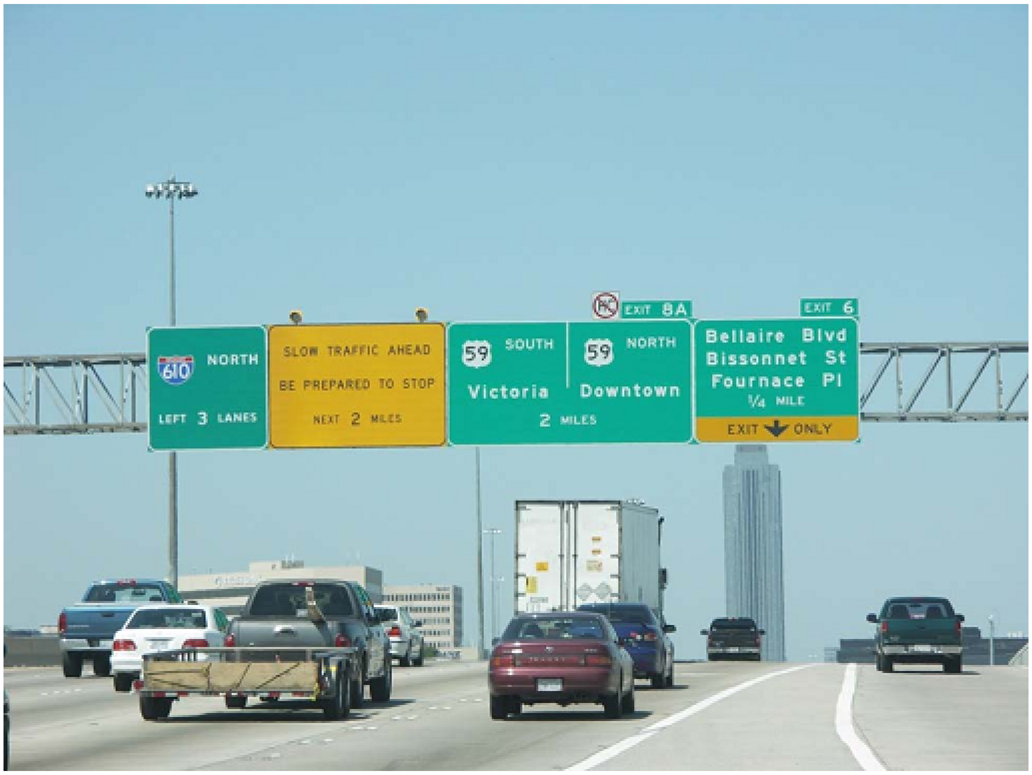


Figure 26: Static Queue Warning Sign on IH-610 in Houston
(Source: Pesti et. al).

6.5 Dynamic Message Sign for Information Dissemination

Dynamic message signs typically display messages for many traffic related reasons including incidents, travel time, planned roadwork, planned special events, natural disasters, AMBER alerts, and public service announcements. These reasons play a role in determining the type of message to be deployed on the DMS. DMS are directly connected to the traffic management center, and the messages can be directly constructed and disseminated remotely. DMS can also be overwritten in case of competing messages for information dissemination.

The message selection can be determined from the available information. As mentioned, the typical DMS in Austin contains three lines and 18 characters per line.

With regards to the queue warning system, the TMC has several options to put on each line of the DMS; these include presence, length, location, and warning. Caution must be exercised as to the total number of characters that each message will require, and the space available on the DMS.

Intent	Sample Message
Presence	• QUEUE AHEAD • CONGESTION AHEAD
Length	• FOR THE NEXT XX MILES
Location	• FROM XX TO XX • START AT XX
Warning	• BE PREPARED TO STOP • SLOW DOWN • WATCH FOR COLLISIONS

Table 17: Examples of Messages on the DMS.

The DMS message may also change based on the roadway conditions and the time of day; a congestion related message would only be displayed during the peak hours, and public service announcements or special events may be mentioned otherwise.

Obviously different messages have varying levels of importance. In many cases, a hierarchy is needed to sort the messages in decreasing levels of priority. In its design of DMS, the Texas Transportation Institute has devoted an entire section to determining the priority and recommending protocol for the DMS message when competing needs arise. The competing needs may include the following, according to TTI:

- Major accident
- Minor accident
- Construction project
- Construction project with temporary lane closure
- Disabled vehicle blocking a lane
- Incident requiring lane closure

- Incident requiring total freeway closure
- Maintenance operations with lane closure
- Maintenance operations requiring total freeway closure
- Special event exit
- Adjoining state accident
- Adjoining state maintenance operations require total freeway closure
- Adjoining state incident requiring total freeway closure (Dudek, 2006).

The traffic management center must determine the hierarchy level for displaying messages on the DMS. In the design of the queue warning system for IH-35 between Riverside and SH-71, an example hierarchy for DMS messages during peak periods would be:

- Lane or exit closure (any type – construction, maintenance, incident)
- Queue warning
- Public service announcement

The rank of the queue warning would be the same for any sort of ITS or ATM deployment – travel time, speed harmonization. Ideally the DMS would be in use at all times, with no messages only during times of repair or updating.

6.6 System Performance

As with any ITS or ATM strategy, a queue warning system must be continually maintained and evaluated for system performance. Some of the possible benefits of a queue warning system are improvements in safety, traffic flow, and travel time. Safety improvements in the queue warning system can be seen as a reduction in collisions, especially rear end and sidecar collisions. Improvements in traffic flow may be seen as increases in average speed, or a move toward more uniform speed. Travel time reductions may also occur, although the difference may be diminutive if existing conditions were already near saturation, as is the case on Interstate 35 between Riverside Drive and State Highway 71. In addition, the benefits from the queue warning system may not be fully understood immediately, but instead can be well documented after sufficient experience. Each potential benefit has a different performance measures for the queue warning system and assessment is dependent on the transportation agency's expectation from the strategy.

Finally, an addendum to the original queue warning system on Interstate 35 is a coordinated use of the frontage roads alongside IH-35 to increase capacity and vehicle throughput. There have been several studies that looked at the operations and capacity of the northbound IH-35 frontage roads between Riverside Drive and Slaughter Lane to address route diversions from the main lanes. Parallel corridors such as Congress Avenue have also been examined. The use of frontage roads and parallel corridors alongside IH-35 can be examined as a coordinated system to perhaps further travel time improvements and enhance system performance and mobility. The next chapter presents a simulation of the queue warning system on IH-35, and a coordinated frontage road network, along with testing and analysis.

Chapter 7: Simulation

7.1 Introduction

This section details the simulation of the proposed queue warning system on Interstate 35 between US-290 / 71 and Riverside Drive. The simulation models both the freeway itself and the parallel frontage roads. A simulation tests the proposed queue warning system to demonstrate the possible effects and ideal setup specifications. The goal of the simulation is to demonstrate the use of a queue warning system to notify vehicles of approaching queues, and the possible use of the frontage roads as an additional route diversion. The simulation can also display the optimal positioning and locations for many of the system components in the freeway segment. This section looks at the queue warning system from an operations perspective.

First the background on the simulation will be provided, particularly the type of software chosen and an explanation for the inclusion of the frontage roads. The methodology of the simulation is then discussed, which includes the gathering of field data and the VAP coding. Next the results from the simulation are shown, with an analysis of the findings. Finally, the section concludes with a summary that also features comments and suggestions for improving the system.

7.2 Background

To perform the simulation, several software packages were considered for their different applications. These software packages ranged from CORSIM to model arterial movement and TRANSYT-7F to optimize arterial signal progression along the frontage road. In the end, VISSSIM by PTV America was chosen to model and run the simulation for this project. VISSIM is a private microsimulation software program that models different roadway networks using customizable traffic features and physical details. VISSIM can be used to model the roadway using existing conditions, and then show the potential results of the roadway after the implementation of a queue warning system.

Frontage roads are included in the simulation. They are included in the simulation to show a coordinated network between the interstate and the frontage roads to improve traffic operations in the corridor. This project is interested in the deployment of a queue warning system for both safety and operational improvements, and the frontage roads can be used to increase the capacity or serve as a route diversion from the main highway corridor. The use of the frontage roads as a route diversion also has a practical application during construction work that may affect the capacity and safety along the main interstate roadway. In a project meeting with the Austin district of TXDOT on the proposed queue warning system, officials noted the system's potential role in diverting traffic in the upcoming construction simultaneously along 100 miles of IH-35.

7.3 METHODOLOGY

7.3.1 Building the Network

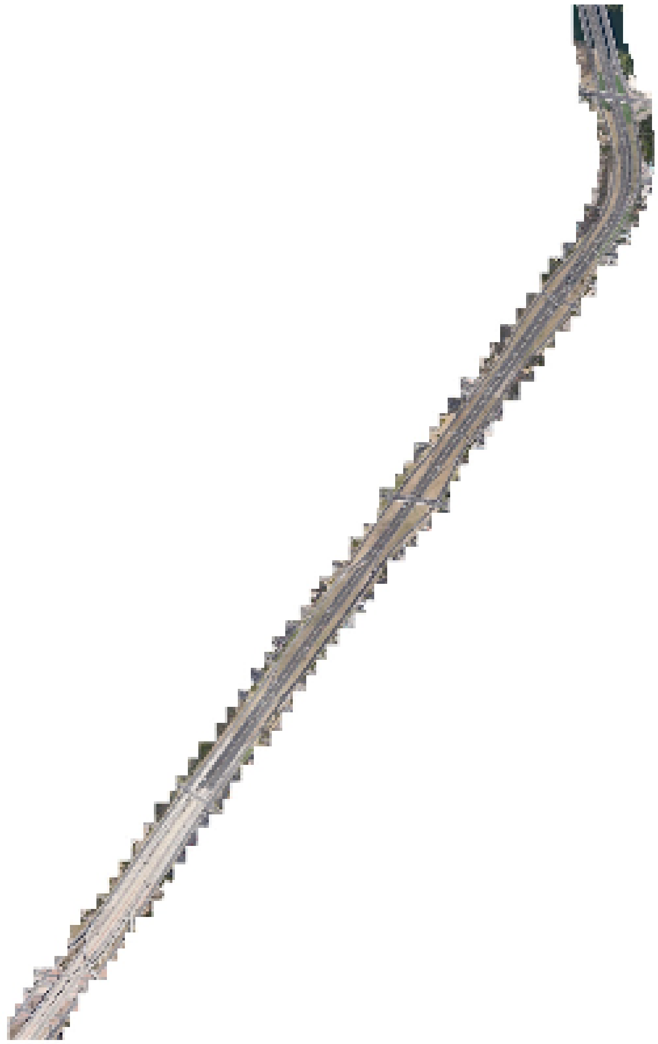
VISSIM consists of making a road network using links and connections. As mentioned, the model is comprised of the northbound IH-35 and the parallel frontage roads. These links and connectors have numerous design parameters and classifications; they include road classification, vehicle composition (passenger cars, trucks, buses, etc), length, width, width of lane, grade, elevation, and more. The links can also be configured to match the plan features of the roadway, such as the large horizontal curve in the section. The model also required exit and entrance ramps to determine routing behavior for vehicles in the segment.

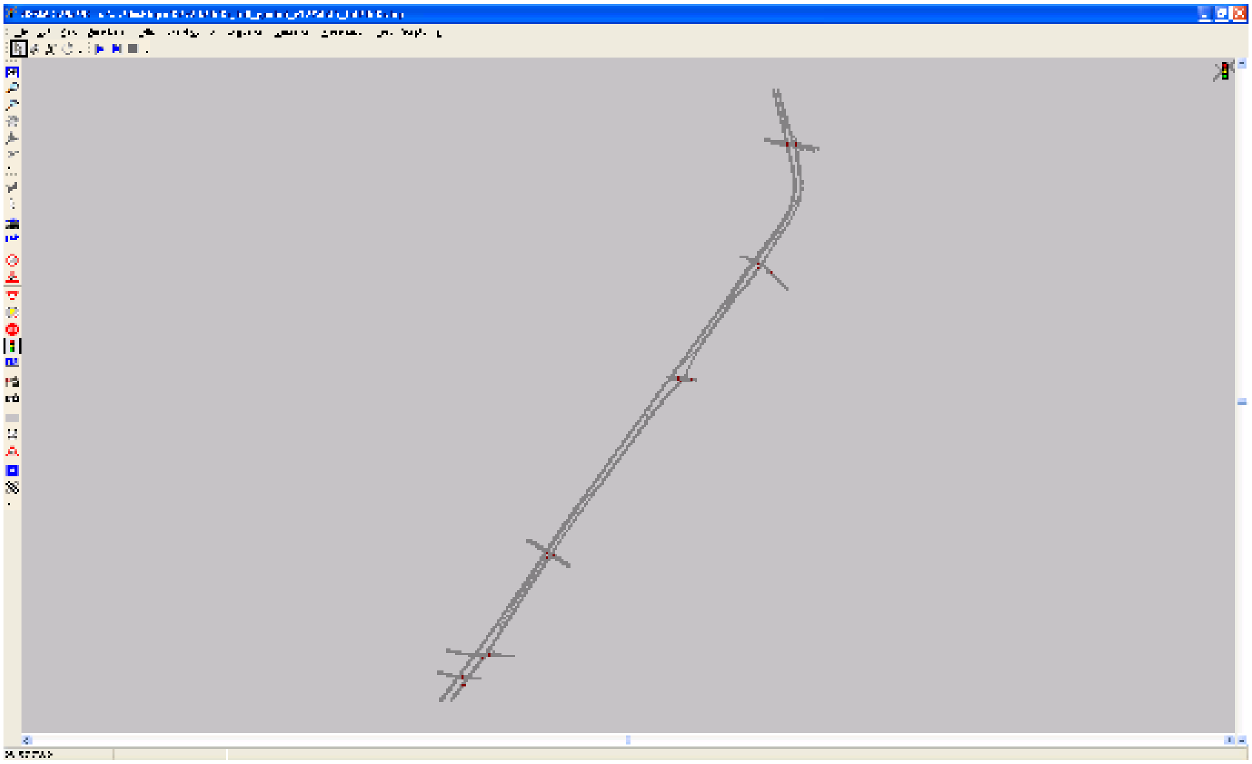
Additionally, the network also included six cross streets that had signals with the northbound frontage roads. These streets each create a four way signalized intersection with the frontage roads and must be taken into consideration when determining operational capacity of the road network. These six streets are:

- Riverside Drive
- Woodward
- Oltorf
- Woodside
- 71E
- 71W

Traffic was counted for each of these streets, most notably the turn counts onto the frontage roads. VISSIM has the capability of configuring a signal timing or accommodating field input. For this model the signal timing was determined with the frontage road as an arterial. The model also contained entrance and exit ramps to allow vehicles access between the interstate and the frontage road.

To build the model, a Google Maps image of the highway section was transposed onto the VISSIM background. The links were built to match the roadway features, including curve geometry, entrance and exit ramp locations, and number of lanes at each interchange. Elevations were not entered in the model.





Figures 27 & 28: Google Map Rendition of IH-35 Segment and VISSIM Model

7.3.2 Field Data Gathering

The next step in building the VISSIM model involves entering traffic data and parameters. Accurate field information is critical to making the model as realistic as possible. The data needed consisted of traffic information for both the interstate and the frontage roads. To find the data, different sources were consulted for each section. The model simulates northbound IH-35 during a work day peak hour. For the project, this is considered between 7:30 AM and 8:30 AM any weekday.

Traffic counts and traffic signals for the frontage roads were gathered on the mornings of Wednesday, June 8, and Thursday, June 9. They were counted for 10 minutes between 7:30 AM and 8:30 AM at each of the aforementioned cross streets. The counts occurred at both east-west directions for the cross street and northbound for the frontage road. The counts include straight through, left turn, and right turn, where possible. It must be noted that while the frontage roads were largely congested, the traffic counts took place during the summer, when school at the University of Texas is not in session. The school is north of the freeway segment and constitutes a large amount of traffic destinations for work and school. The traffic counts are noted below.

Riverside Drive	**Left Turn**	**Straight Through**	**Right Turn**	**Total**
Eastbound (Percentage)	40 (38)	65 (62)	--	105 (100)
Westbound (%)	--	140 (45)	170 (55)	310 (100)
Northbound IH-35 Frontage Road (%)	61 (33)	98 (54)	24 (13)	183 (100)

Woodland Avenue	**Left Turn**	**Straight Through**	**Right Turn**	**Total**
Eastbound (Percentage)	14 (67)	7 (33)	--	21 (100)
Westbound (%)	--	37 (62)	23 (38)	60 (100)
Northbound IH-35 Frontage Road (%)	24 (17)	111 (80)	4 (3)	139 (100)

Oltorf Street	**Left Turn**	**Straight Through**	**Right Turn**	**Total**
Eastbound (Percentage)	65 (46)	75 (54)	--	140 (100)
Westbound (%)	--	141 (71)	58 (29)	199 (100)
Northbound IH-35 Frontage Road (%)	97 (32)	128 (42)	80 (26)	305 (100)

Table 18: Traffic Counts during Peak Hours
(Counted for 10 minutes).

Woodward Street	**Left Turn**	**Straight Through**	**Right Turn**	**Total**
Eastbound (Percentage)	31 (30)	71 (70)	--	102 (100)
Westbound (%)	--	26 (51)	25 (49)	51 (100)
Northbound IH-35 Frontage Road (%)	28 (15)	144 (80)	10 (5)	182 (100)

71 West	**Left Turn**	**Straight Through**	**Right Turn**	**Total**
Eastbound (Percentage)	--	--	--	--
Westbound (%)	--	108 (86)	18 (14)	126 (100)
Northbound IH-35 Frontage Road (%)	254 (50)	252 (50)	--	506 (100)

71 East	**Left Turn**	**Straight Through**	**Right Turn**	**Total**
Eastbound (Percentage)	40 (34)	76 (66)	--	116 (100)
Westbound (%)	--	--	--	--
Northbound IH-35 Frontage Road (%)	--	364 (77)	111 (23)	475 (100)

Table 18: Traffic Counts during Peak Hours
(Counted for 10 minutes).

Signal timing was also included in the model design. As mentioned, there are six intersections with traffic signal on the IH-35 northbound frontage road. In VISSIM, the signal timing is configured by having a signal control category for each intersection. Each signal control has a number of signal groups that represent the different phases in the cycle. The signal group can be configured to have the number of phases, amount of green time, type of traffic signal, and total cycle time, to name a few.

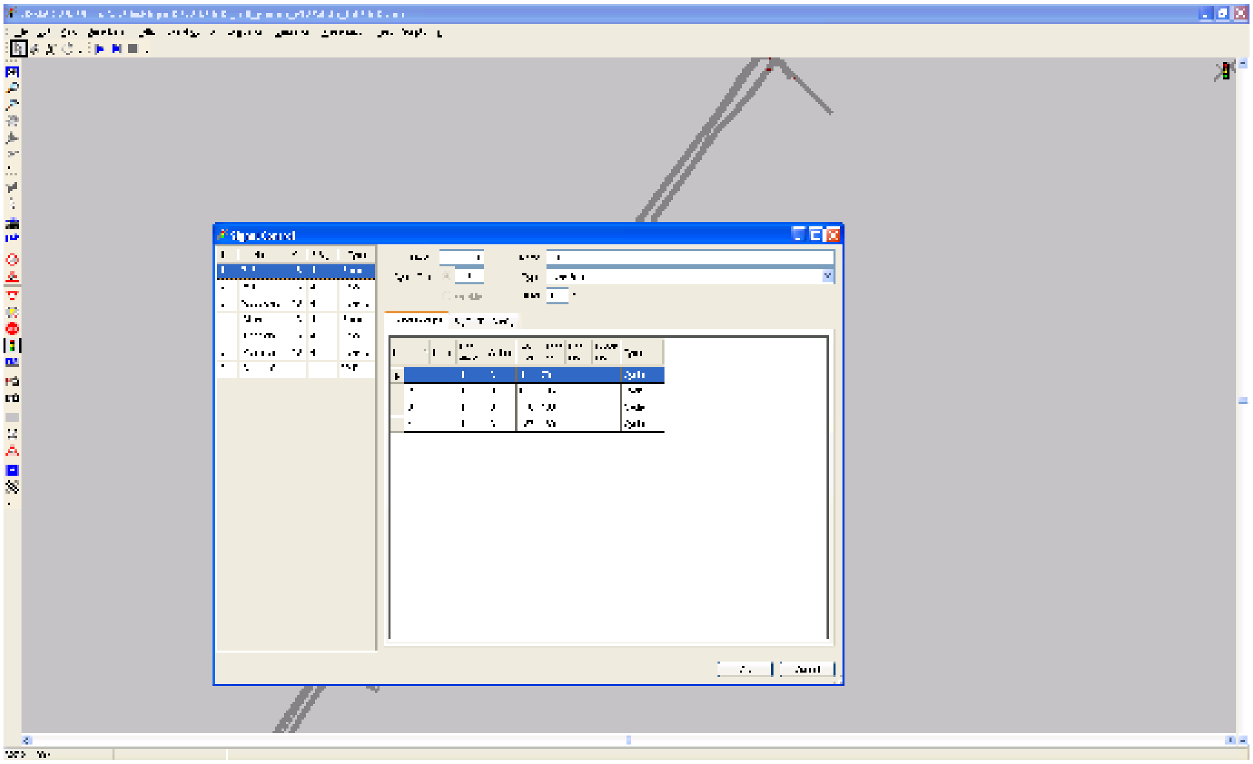


Figure 29: Signal Timing Setup on VISSIM Model.

The signal timings for each of the signalized cross streets in northbound direction were gathered and are listed as follows:

Intersection	**Total Cycle Time (Min:Sec)**
Riverside Drive	2:15
Woodland Avenue	1:15
Oltorf Street	2:10
Woodward Street	2:10
71 West	2:40
71 East	2:40

Table 19: Signal Timings during Peak Period

For the model, the signals were classified as fixed time controllers with the above cycle times at their respective intersections. Each of the signal controllers had four timing sequences (red/amber, red, and green), one for each direction. Although the intersections only have vehicles moving in the northbound direction along the frontage road, timing was still allocated for traffic flow in the southbound direction to arrive at the intersection and cross. In addition to the six signal controllers, the model also contained a seventh signal controller for the queue warning system. This controller was classified as a VAP (Vehicle Actuated Programming), which was configured using the model's queue warning system. An explanation of VAP will be made in a later section. Improvements may be made to the model by assigning more accurate classifications to the traffic signals and using field-gathered phasing sequences.

The next step is to enter hourly vehicle counts for all the links in the model – IH-35, the cross streets (both eastbound and westbound), and the frontage road. All of the vehicle counts with the exception of the main freeway are based on aforementioned traffic information gathered at the intersections. The traffic data was counted in all the directions for 10 minutes during the AM peak period. The count is subsequently multiplied by 6 for an hourly count and rounded to the nearest appropriate number for the link. As noted previously, these counts were performed in June, which is a summer month and thus may be deflated from higher numbers during the UT school year that may be more representative of a typical morning period.

Traffic counts for IH-35 northbound were determined using AADT counts gathered from the Central Area Metropolitan Planning Organization website. AADT, which stands for average annual daily traffic, represents the average traffic for that highway section on a regular day for that particular year. The project used the 2009 Traffic Count Map from the CAMPO website (the most recent one) to determine an

AADT count of 171,000 vehicles for the section (CAMPO, 2009). The actual value was generated using the Directional Design Hourly Volume formula, which consists of:

$$DDHV = AADT \times K \times D$$

Where

> $AADT$ = Average Annual Daily Traffic, or 171,100 vehicles.
> K = Peak hour percentage, which ranges between 7 and 12 percent. Here the mean, 9.5 percent, is taken
> D = Directional percentage, which ranges between 50 and 60 percent for urban areas. The northbound here is given as 55 percent.

Multiplying, the DDHV is found to be 8935 vehicles across three lanes of northbound IH-35 traffic during the peak hour. However, the maximum traffic for three lanes on a freeway during peak hour cannot be more than 7500 vehicles. The VISSIM model was run with the calculated value of 8935 vehicles, which yielded higher occupancy rates, lower speeds, and greater travel times in the entire network. A lower rate of 7500 vehicles per hour would have lower occupancy rates, higher speeds, and shorter travel times.

In addition to determining traffic counts on the frontage roads and the main freeway, the truck percentage was another figured that was calculated an inputted into the VISSIM model. The truck percentage refers to the percentage of heavy goods vehicles on the freeway. The default HGV percentage in VISSIM is 2 percent; that is, 2 percent of the vehicles on the roadway are HGV, with the remainder being other types of vehicles. However, Interstate 35 in Texas is a well known trade corridor between the United States and Mexico, and the truck percentage is higher than 2 percent. The Texas Department of Transportation provided a roadway inventory file that contained the truck percentage of average daily traffic at different milepoints between SH-71 and Riverside Drive. The values ranged from 14.9 percent to 10.3 percent, with an average of 10.5 percent. Before determining the actual truck percentage on the Austin segment, the VISSIM model was run using the default truck percentage of 2 percent. The model was rerun with the original base conditions with the updated truck percentage, and it was found that while the occupancy rates were higher, the network performance measures such as travel times and average delay did not have significant differences from the original results.

7.3.3 Routing

The next step in building the VISSIM model is designing the routing patterns. In VISSIM, routing is defined as the different link paths a vehicle may choose based on the given parameters. At an intersection, a vehicle may choose to go straight through, or make a left or right turn. On IH-35, a vehicle may choose to remain on the freeway, or exit on to the frontage road. Conversely on the frontage road, a vehicle may choose to remain or enter IH-35. The user specifies the percentage of vehicles choosing each route. For each of the cross streets at the frontage road intersections, this is determined here from the field observations mentioned in the previous section.

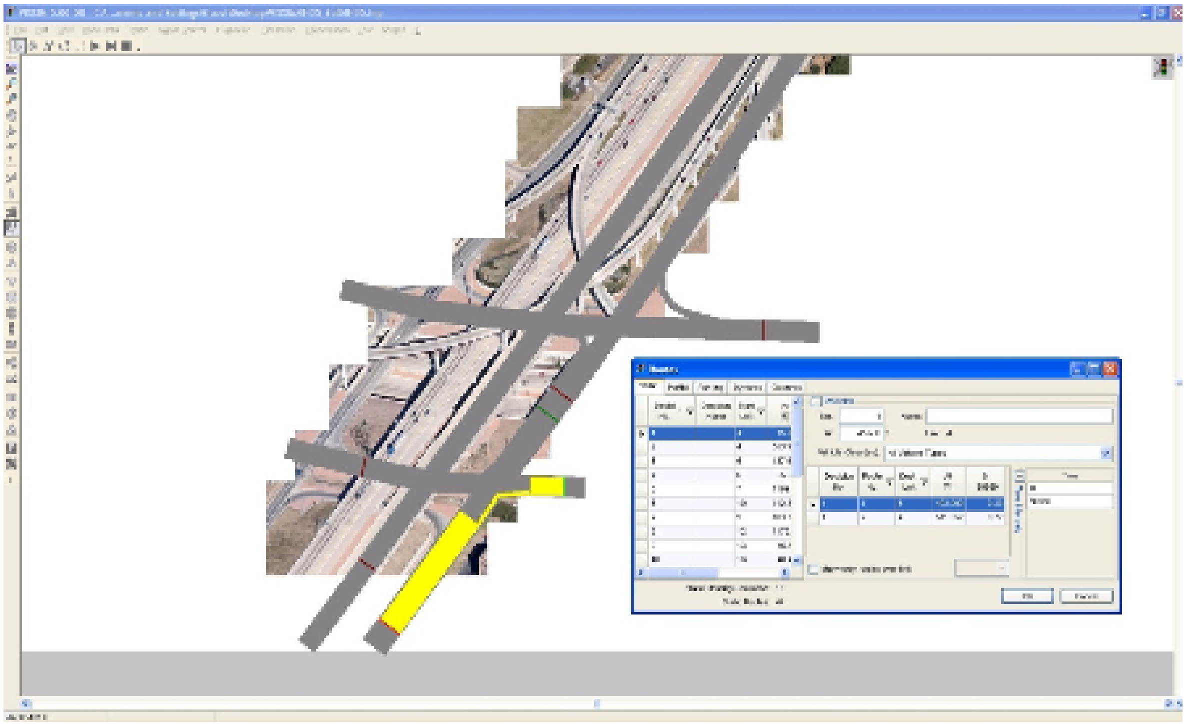


Figure 30: Example of Routing on VISSIM

Meanwhile, determining routing trends for entering and exiting IH-35 is trickier. On IH-35, a vehicle may exit right before the cross street it wants to turn onto, or it may exit prematurely and travel on the frontage road. Conversely, a vehicle may enter IH-35 from the frontage road as soon as possible, or choose to travel on the frontage road and enter the freeway further downstream. Initial numbers of the turning ratio were computed by taking the percentage of vehicles in the northbound direction at the intersection nearest to the exit and comparing it to the number of vehicles in a single lane on IH-35 (approximately 7500 divided by 3, or 2500). One of the objectives of the proposed queue warning system is to determine the percentage of vehicles that switch between the freeway and the frontage road at the exits and entrances. This is known here as the diverging rate, and may be used to assess the number of vehicles that may utilize route diversion.

7.3.4 Simulation Testing

The simulation testing of the queue warning system was performed to identify three factors to improve the design: location of the detector(s), occupancy rate to trigger the queue warning system, and vehicle diverging rates. The base scenario for the simulation is occupancy rate of 0.12 (with a speed limit of 45 mph), detectors located right at the middle of the curve, and a diverging ratio of 20:1:1:1 for staying on the freeway, exiting before Woodward Avenue, exiting before Riverside Drive (and the curve), and exiting after the curve, respectively. When one of these was tested, the other factors were held constant. Five tests were made for each outcome. For each test the simulation was run 7 times to account for the random-ness, and the averages were taken and reported as the results. Further testing may be performed combining the best outcomes from each scenario to see their combined effect on overall performance.

Results from each scenario for each of the 3 factors were compiled and entered into one of three tables. The tables present the travel times for the different identified routes, the network as a whole, and the intersections. The travel times were measured on VISSIM by marking the start and stop locations on the model. VISSIM also counted the number of vehicles that passed the start and stop locations for each travel time location.
The route table identifies travel times in the following areas:

- Travel time on IH-35, freeway only (FREEWAY)

- Travel time on IH-35, both freeway and frontage road (FREEWAY – FRONTAGE ROAD)
- Travel time on IH-35, frontage road only (FRONTAGE)

Meanwhile, network performance variables include:

- Occupancy rate
- Speed
- Average delay time per vehicle
- Average speed
- Average stopped delay per vehicle
- Average number of stops per vehicle
- Total delay time
- Total travel time

The intersections are numbered accordingly moving northbound on IH-35:

Intersection	Cross Street
1	71E & 71W
2	Woodward Street
3	Oltorf Street
4	Woodward Avenue
5	Riverside Drive

Table 20: Intersection Assignments

For each intersection, travel time zones were established in each direction on both the frontage road and the cross street. Over the 2 hour period, the model collected travel times on all of the zones, along with the vehicle counts. The weighted average was taken of all the travel times at each intersection to show how the intersection would be affected by the additional vehicles on the frontage road. It is predicted that the use of the queue warning system and the diversion of vehicles would have a negative impact in level of service and travel times at the intersections, especially at the busier cross streets such as Oltorf and Riverside.

7.3.5 VAP

VAP stands for Vehicle Actuated Programming, and refers to the part of VISSIM that creates unique programs and scenarios to be simulated or tested. The user is able to specify certain commands and input variables to the program. A queue warning system program was written to specify the routing behavior of vehicles to be diverted from the main highway to the frontage road. The program contained occupancy rate numbers and speed limit values, as well as routing commands and diversion percentages as gathered from field data reports. This is the percentage of vehicles that exit from the IH-35 freeway onto the frontage road using different exit ramps.

The logic for the queue warning program was based on the activation of the detector and the subsequent distribution of traffic onto the frontage road. According to the code, the detector is activated when both the occupancy rate and detected speed are beyond a preset threshold. The occupancy rate is the percentage of time that vehicles occupy a travel lane. It is similar to the concept of traffic density in that it may be an indication of congestion. The speed limit is used as an additional condition because like density, very low and very high values of traffic occupancy negatively affect flow conditions. The queue warning system is represented by a change in the percentages of vehicles traveling various routes on Interstate 35. Fewer vehicles may be inclined to stay on IH-35 with a queue warning system, and instead choose to travel on the frontage road. The program makes a provision for vehicles to exit before the curve at Riverside. The full VAP code can be found in Appendix A.

7.4 Results & Analysis

Three design parameters (detector location, occupancy rate / speed, and diverging rate) with 5 scenarios each were run in VISSIM. For each scenario, VISSIM was run 7 times with a different random seed generator to account for variability in the results. The average of the 7 tests were taken and presented as the result for the scenario. An example spreadsheet detailing the VISSIM results of one of the design parameters can be found in Appendix B of this report.

7.4.1 Detection Location

Recommended design guidelines for the spacing of detector equipment vary depending on the type of equipment used. The location of the detector is critical to detecting the site of the congestion. For each, detection equipment was placed one of five different locations along the highway section. A detector was placed across each lane of the highway, and all were connected to the same queue warning program. The five detector locations can be seen in the following map:

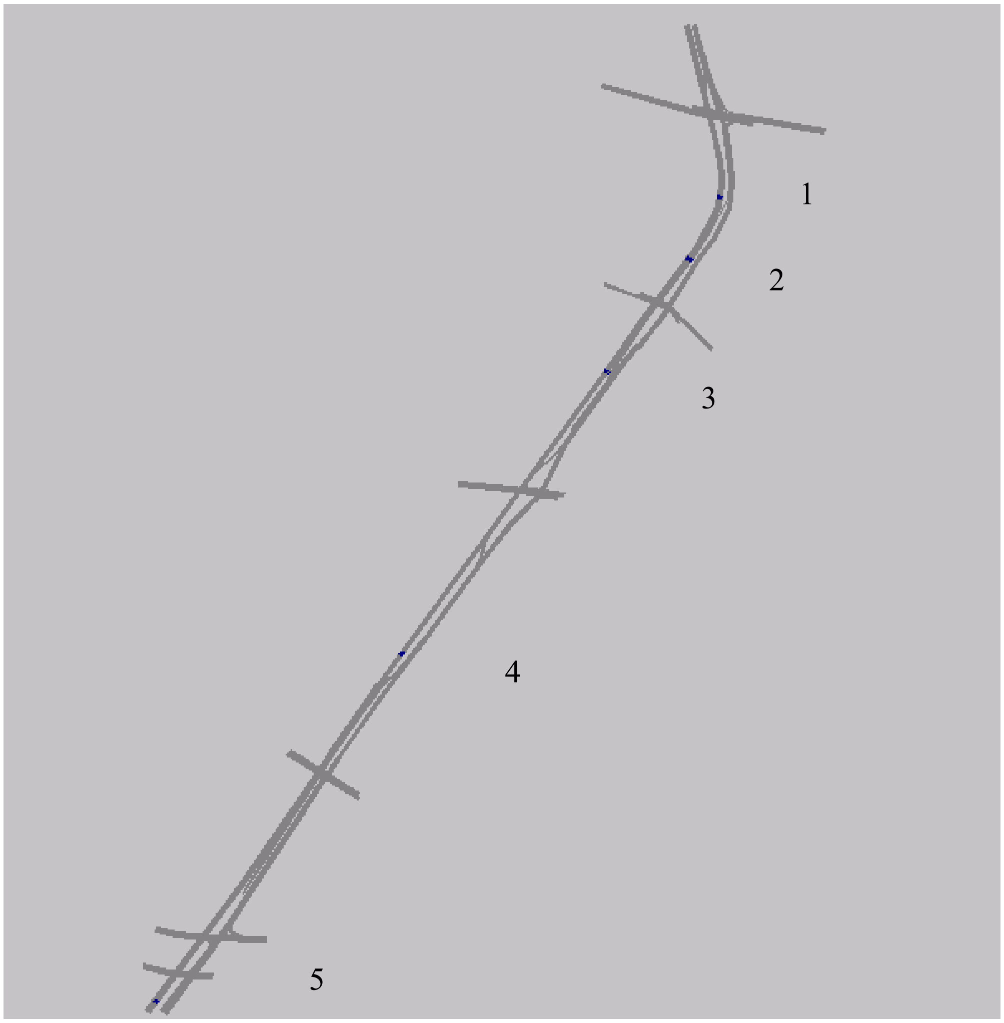


Figure 31: The 5 Sites Tested for Detector Deployment

The map indicates that scenario one was located right at the curve, scenario two at the start of the curve and sites 3, 4, and 5 are located about 1000 feet, 1 mile, and 2 miles away from the start of the curve, respectively.

Findings from the detector tests are reported in the following table:

Scenario	Travel Time on IH-35 FREEWAY TRAVEL TIME, s	Travel Time FWY – FRONT ROAD	Travel Time FRONT – FRONT	Intersection all (weighted avg)
1	339.1	346.97176	524.6	39.8153395
2	326.4	334.86505	464.3	39.7670640
3	313.8	324.75347	487.2	40.1806297
4	335.5	339.21588	528.2	39.2639517
5	322.6	330.33572	522.6	39.6364430

Table 21: Route Results, Detector

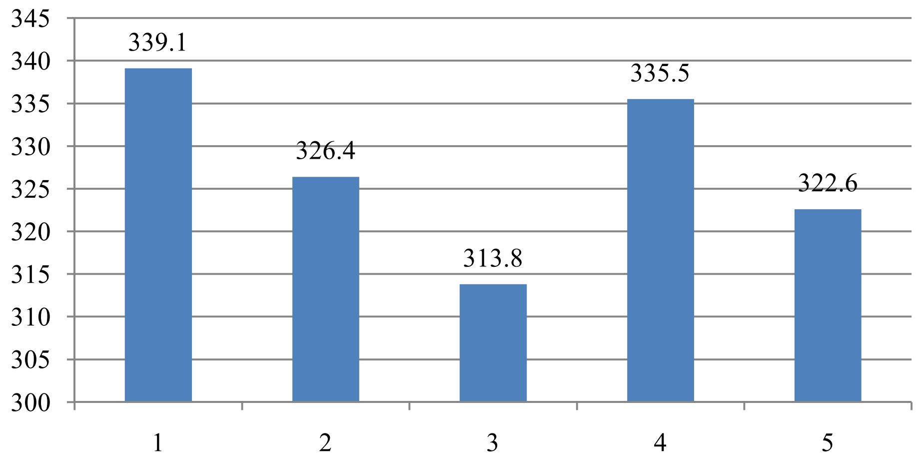
Scenario	Occupancy Rate	Speed (mph)	Avg Delay Time per Veh (s)	Avg Speed (mph)	Avg Stopped Delay per Veh (s)	Avg # Stops per Veh	Total Delay Tim (hr)	Total Travel Time (hr)
1	14.8	21.8	115.181	15.583	41.831	1.481	333.816	639.000
2	14.9	21.8	110.378	15.895	41.746	1.381	319.969	626.384
3	14.2	22.9	103.531	16.441	39.669	1.288	303.124	613.018
4	14.6	22.2	112.012	15.810	40.652	1.437	324.939	630.958
5	14.3	22.3	108.888	16.054	41.122	1.356	318.078	628.010

Table 22: Network Results, Detector

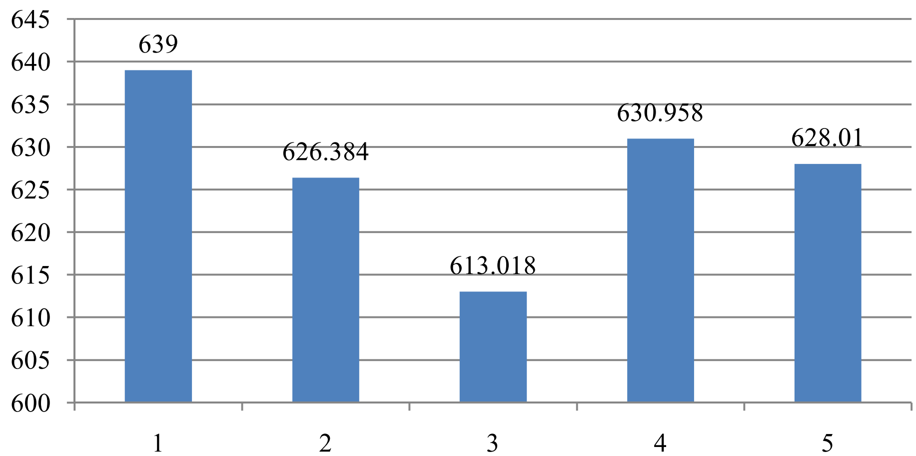
Scenario	Intersection 1	Intersection 2	Intersection 3	Intersection 4	Intersection 5	Intersection all
1	33.045601	48.116431	45.84714	50.9440651	35.2482582	39.8153395
2	33.109984	46.710282	46.656297	52.101848	34.6862061	39.7670640
3	33.127278	60.973967	45.173039	50.924988	34.847893	40.1806297
4	33.4678068	47.1959451	44.8745085	51.4910595	34.3947694	39.2639517
5	33.2350758	48.1150219	46.5270253	52.1958003	34.1118088	39.6364430

Table 23: Intersection Results, Detector

Freeway Travel Time (s)



Total Network Travel Time (hr)



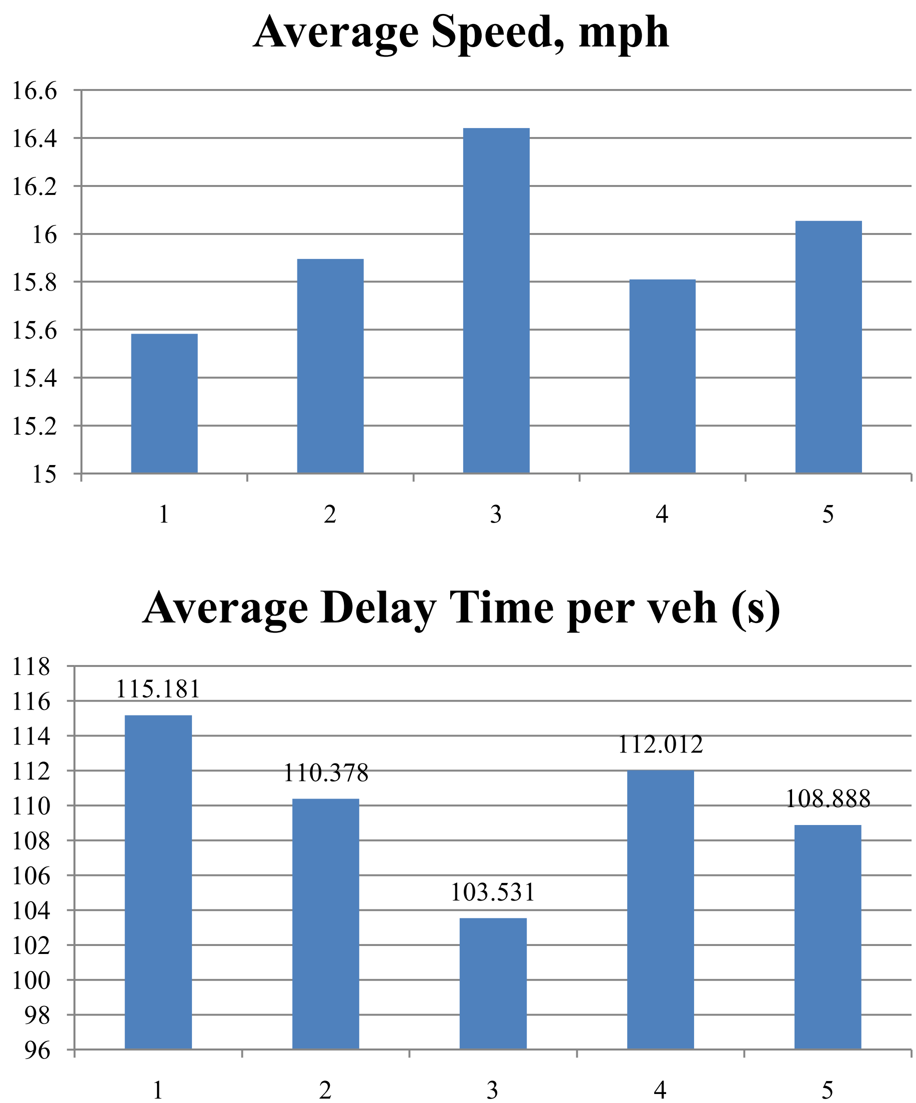


Figure 32: Select Performance Measures for Detector Location

From the simulation results, the detector location in scenario 3 has the best results of the 5. Scenario 3, which is about 1900 feet south of Oltorf, has the shortest travel time in all of the performance measures and the travel times. This scenario also has the greatest weighted average travel time for all of the intersections. On the freeway, a detector at location 3 would be have the shortest travel time at 313.8 seconds (about 5.25 minutes).

At the same time, scenario 3 also has the smallest occupancy rate and greatest average speed, at 14.2 and 16.4 mph, respectively.

7.4.2 OCCUPANCY RATE / SPEED LIMIT

The occupancy rate, which is determined by the detector, provides an assessment of the traffic conditions when combined with the speed limit. The occupancy rate is the percentage of time vehicles occupy a travel lane. It is a spot measurement of density, and is measured as the traffic density multiplied by the effective vehicle length. Traffic flow is a function of density; flow may be zero when density is zero or near zero or at maximum density. The occupancy rate is inversely related to speed; as the occupancy rate increases speed decreases.

For the model, five scenarios of varying occupancy rates and speed limits were tested as triggers for the queue warning system. In the .VAP program, the queue warning system and route diversion is activated when the detected occupancy rate is above a minimum level and speed is below a minimum value. The default occupancy rate and speed limits are 0.12 and 45 mph, respectively. The five scenarios tested are as follows:

Test	Occupancy Rate	Speed Limit (mph)
1	0.12	35
2	0.18	35
3	0.18	45
4	0.20	35
5	0.20	45

Table 24: Tested Scenarios for Occupancy Rate, Speed Limit

Findings from the occupancy tests are reported in the following table:

Scenario	Travel Time on IH-35 FREEWAY TRAVEL TIME, s	Travel Time FWY – FRONT ROAD	Travel Time FRONT – FRONT	Inters all (weighted avg)
1	224.8	224.705396	437.4	32.2035
2	229.0	230.596376	393.9	31.9340
3	220.2	220.382630	448.8	32.3426
4	232.0	230.741116	432.4	32.3368
5	217.5	219.509052	439.8	31.8378

Table 25: Route Results, Occupancy Rate

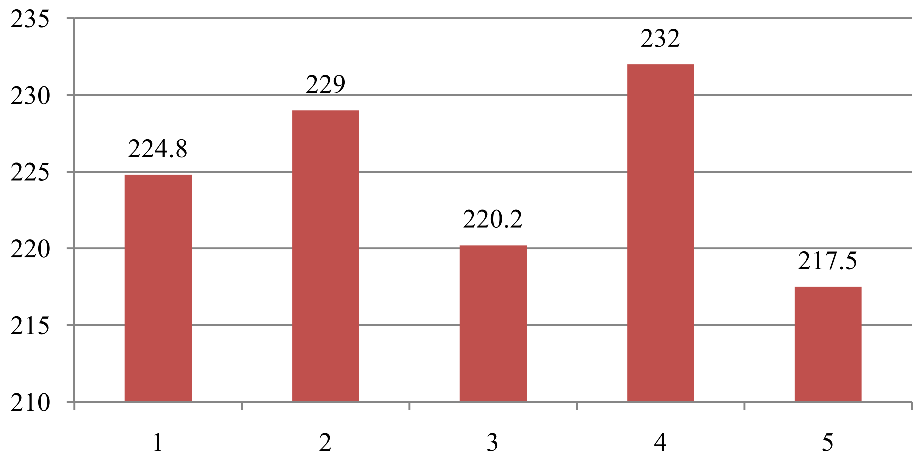
Scenario	Occupancy Rate	Speed, mph	Avg Delay Time per Veh (s)	Avg Speed (mph)	Avg Stopped Delay per Veh (s)	Avg # Stops per Veh	Total Delay Tim (hr)	Total Travel Time (hr)
1	11.5	33.5	85.843	23.039	28.984	0.800	276.321	493.025
2	11.9	32.6	86.924	22.759	28.890	0.819	280.882	495.580
3	11.4	34.8	83.451	23.536	28.003	0.749	272.123	493.239
4	11.9	33.2	88.435	22.577	28.904	0.825	286.463	500.754
5	11.5	34.8	82.126	23.665	28.235	0.752	267.193	487.101

Table 26: Network Results, Occupancy Rate

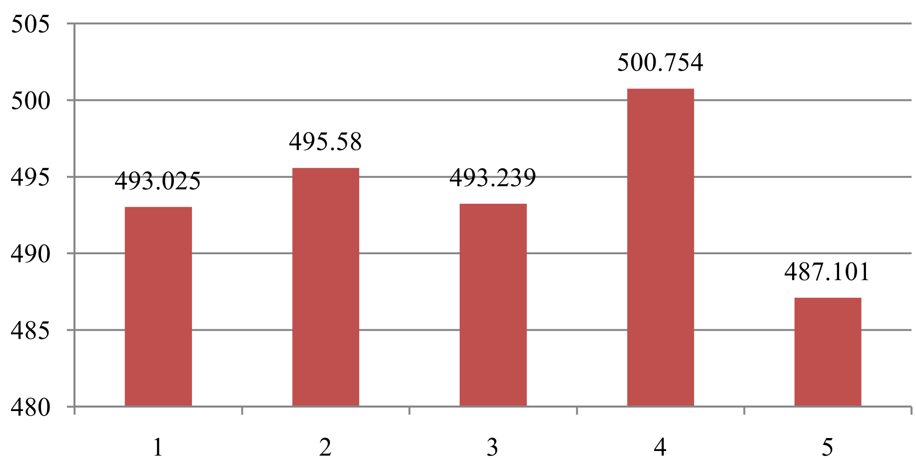
Scenario	Intersection 1	Intersection 2	Intersection 3	Intersection 4	Intersection 5	Intersection all
1	26.0073017	43.8250601	30.0850067	46.9774243	32.0304749	32.2035
2	26.7596084	43.6217244	27.7561481	48.3990645	32.5651201	31.9340
3	27.0219799	43.9333885	28.4993468	47.7793073	33.2218667	32.3426
4	26.5765920	44.5522135	29.7902615	46.4938628	32.4950703	32.3368
5	26.8416967	43.8551165	27.7966396	46.5999140	32.5708029	31.8378

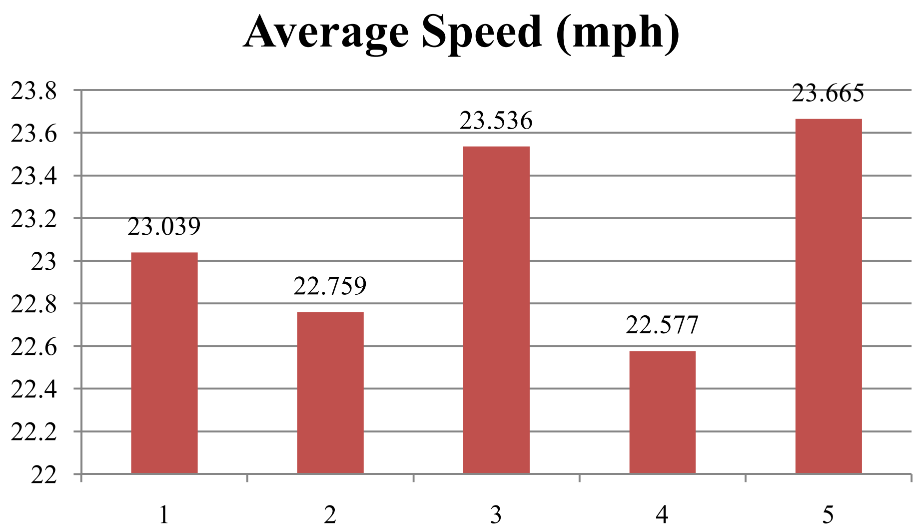
Table 27: Intersection Results, Occupancy Rate

Freeway Travel Time (s)



Total Network Travel Time (hr)





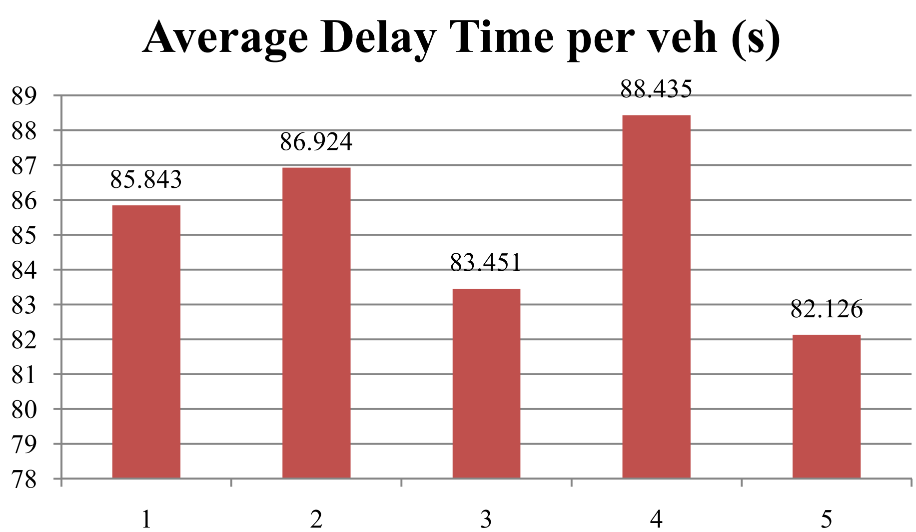


Figure 33: Select Performance Measures for Occupancy Rate, Speed Limit

Unlike the results of the detector tests, different scenarios have different leaders in the travel time results. While scenario 5 has the smallest travel time on the freeway with 217.5 seconds (3.63 minutes) and the freeway-frontage route (219 seconds or 3.65 minutes), scenario 2 has the smallest travel time for the frontage-frontage road at 393.9 seconds (6.57 minutes). Additionally, scenario 3 has the longest average delay of all the intersections. It is also notable that the average speeds for all of these scenarios during the simulation period are all at least 10 mph faster than the detector results. Scenario 5 with 0.20 occupancy rate and 45 mph had the smallest overall travel time.

7.4.3 Vehicle Diverging Rate

The vehicle diverging rate refers to the ratio or proportion of vehicles that would take a certain exit from the freeway main lanes. In a queue warning system where the main freeway was congested, vehicles may be diverted to the frontage road earlier than the destination cross street. The frontage road may provide temporary additional capacity during peak hours. Similarly, a higher number of diverting vehicles onto the frontage road may improve travel times on the freeway, but may also increase delay at intersections on the frontage road.

The VAP program changes the proportion of vehicles taking the various exits when the queue warning system is activated. Vehicles are given the option of remaining on the freeway the entire time, exiting before Woodward Avenue, before Riverside Drive, or after Riverside Drive. The original code has the proportion of exiting vehicles for the four routes at 6:2:2:2, respectively. This means that 50 percent of the vehicles remain on the freeway, 17 percent exit before Woodward Avenue, 17 percent before Riverside Drive, and 17 percent after Riverside Drive. For the tests, changes in the diverging rates are made to the route that travels solely on IH-35 and for the exit before Riverside Drive. The changed diverging rates are (the ratios represent the proportions in the order of the routes mentioned above):

Test	Diverging Rate for Staying on IH-35, exiting on Woodward Ave, exiting before Riverside, exiting after Riverside (Respective ercentages)
1	20:1:5:1 (74%, 4%, 18%, 4%)
2	20:1:10:1 (63, 3, 31, 3)
3	20:1:15:1 (54, 3, 40, 3)
4	15:1:5:1 (67, 5, 23, 5)
5	15:1:10:1 (56, 3.5, 37, 3.5)

Table 28: Tested Diverging Rates

Findings from the diverging tests are reported in the following table:

Scenario	**Travel Time on IH-35 FREEWAY TRAVEL TIME, s**	**Travel Time FWY - FRONT ROAD**	**Travel Time FRONT - FRONT**	**Inters all (weighted avg)**
1	220.6	220.0579	395.0	32.1838
2	218.7	219.0700	444.6	32.0485
3	224.5	217.6438	454.8	32.3086
4	223.1	223.5774	469.0	32.3481
5	223.4	220.4952	391.1	32.3717

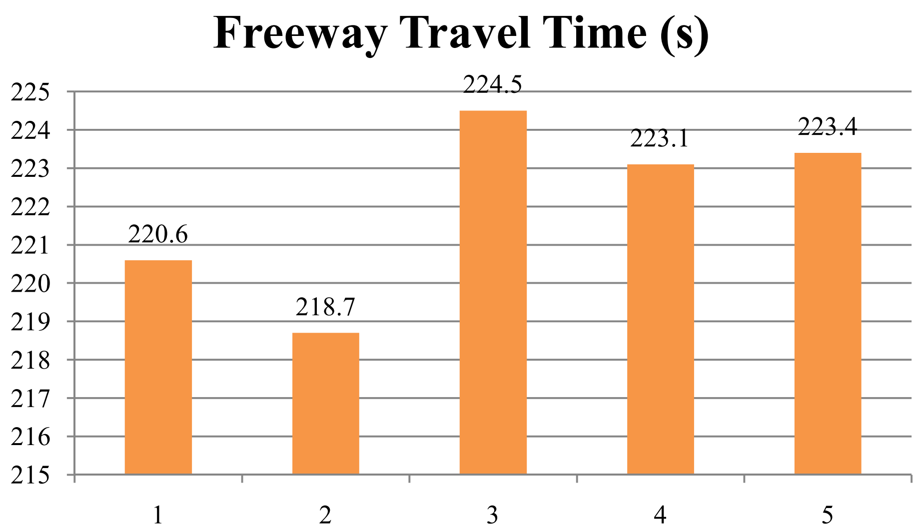
Table 29: Route Results, Diverging Rate

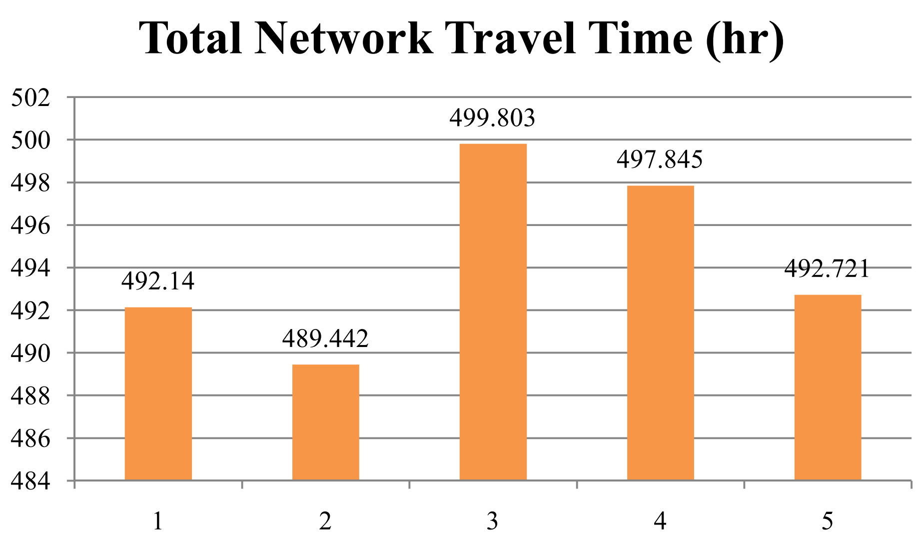
Scenario	**Occupancy Rate**	**Speed, mph**	**Avg Delay Time per Veh (s)**	**Avg Speed (mph)**	**Avg Stopped Delay per Veh (s)**	**Avg # Stops per Veh**	**Total Delay Tim (hr)**	**Total Travel Time (hr)**
1	11.5	34.6	83.330	23.482	27.835	0.745	273.150	492.140
2	11.5	34.4	82.957	23.570	28.365	0.754	269.342	489.442
3	11.5	34.7	85.791	23.162	28.302	0.764	278.996	499.803
4	11.5	35.2	85.171	23.241	28.447	0.764	277.404	497.845
5	11.4	33.9	83.473	23.551	28.075	0.747	271.431	492.721

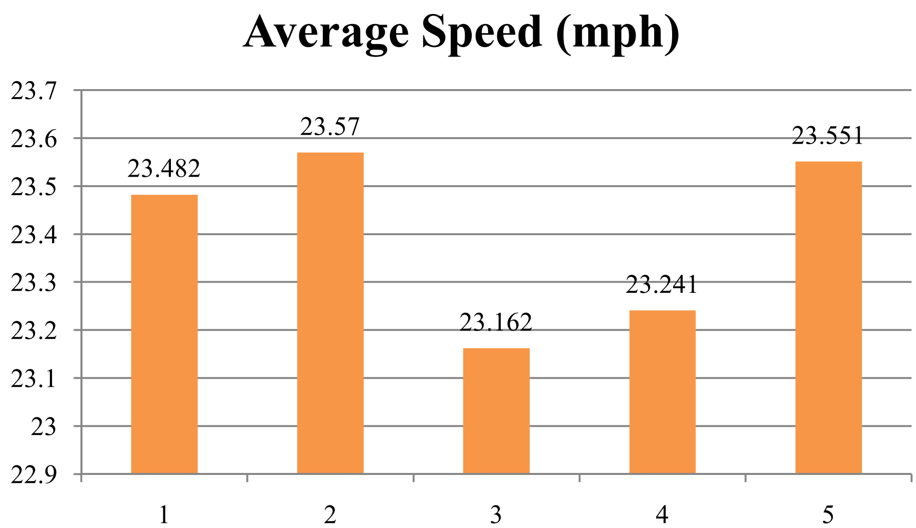
Table 30: Network Results, Diverging Rate

Scenario	Intersection 1	Intersection 2	Intersection 3	Intersection 4	Intersection 5	Intersection all
1	26.704391	43.455414	28.208306	47.687018	33.164474	32.1838
2	27.108061	44.089224	28.000177	47.034320	32.609002	32.0485
3	26.644179	42.691570	29.707957	46.790257	32.658461	32.3086
4	26.710957	43.715521	29.467274	47.359999	32.672540	32.3481
5	26.580690	43.707699	29.501006	47.185100	32.795840	32.3717

Table 31: Intersection Results, Diverging Rate







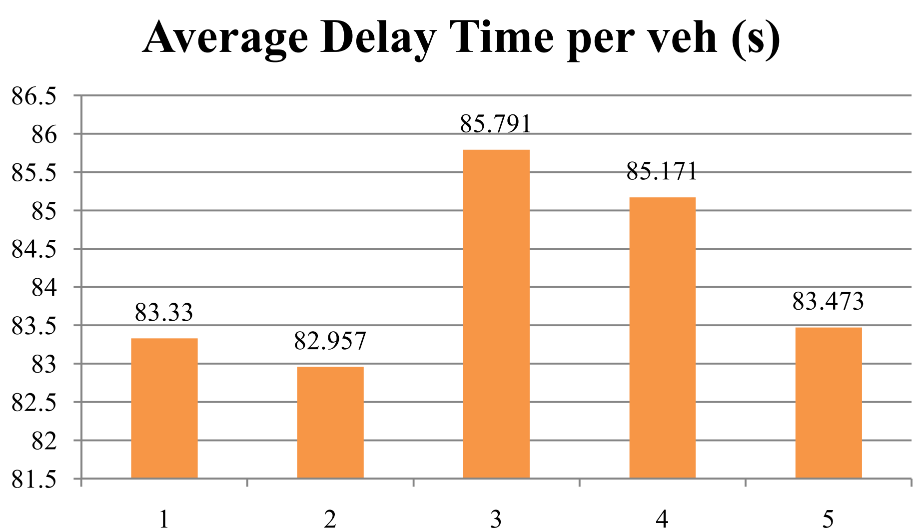


Figure 34: Select Performance Measures for Vehicle Diverging Rate

Similar to the occupancy rate tests, different scenarios perform better in different categories. For freeway travel time, scenario 2 (20:1:10:1) has the shortest travel time, with 218.7 seconds (3.65 minutes). Scenario 2 has fastest average speed at 23.6 mph, but all of the scenarios have an average speed of approximately 23 mph. Many of the scenarios have similar results, and all are improvements over the base case with no queue warning system.

7.5 SUMMARY

This section details a VISSIM simulation of a queue warning system of Interstate 35 between Riverside Drive and State Highway 71. The previous chapter outlined a proposed design for a queue warning system. The VISSIM model does not specify the type of detector or the message sign(s) used. Instead, the .VAP program specifies a certain percentage of vehicles that diverge as a result of the queue warning system. The simulation tested the operational performance of the queue warning system by primarily measuring the travel time across several routes. Improvements in the operational performance may result in a decrease in abrupt stops, which may be a factor in rear end and side car collisions. In addition to measuring the performance of the freeway and frontage roads, the simulation also calculated the impact of additional vehicles at the signalized intersections.

The simulation tested 3 scenarios as part of the queue warning system: the detector location, occupancy rate, and diverging rate. The detector is used to identify the location of the traffic queue, and one location may be better than others in terms of identifying the queue as quickly as possible. The occupancy rate is related to the traffic density and, when combined with speed, provides insight into whether or not the freeway is congested. Finally, the diverging rate represents the percentage of vehicles that reroute after the queue warning system was activated. Each scenario had 5 different cases, and the cases were each run 7 times to account for random error.

Test 3 which had detectors located at about 1900 feet before Oltorf Drive had the shortest travel time at 313.8 seconds (5.23 minutes). However, the scenarios only tested detectors placed in one location in the entire 2.5 mile section. Additionally, all of the detector tests have average speeds below 20 mph with the queue warning system. This is slower than all the other tests for occupancy rate and diverging rate, where the average speeds are near 25 mph or over. Detector placement is recommended at least one every half mile, so future studies may be undertaken to look at placing detectors in multiple locations.

An occupancy rate of 0.20 and a speed limit of 45 mph were found to have the shortest travel time on the IH-35 freeway with 217.5 seconds (3.65 minutes).

The vehicle diverging rate is the percentage of vehicles that choose certain routes off the IH-35 main lanes. In the VISSIM program, the proportions are among staying on the freeway, exiting before Woodward Avenue, before Riverside Drive (and the sharp geometric curve), or after Riverside Drive. In these tests, having a ratio of 15:1:5:1 among the four routes had the fastest average speed, but a ratio of 20:1:10:1 has the shortest travel time on the freeway.

Chapter 8: Concluding Remarks

This report examines the practical application of active traffic management to address a congestion issue. Active traffic management is a group of intelligent transportation system strategies used to address real time, changing traffic conditions. The section of Interstate 35 in Austin between Riverside Drive and State Highway 71 has a sharp horizontal curve, as well as vertical sight distance issues. In addition to persistent congestion, this highway stretch also has numerous vehicle crashes. This report provided a safety analysis of the crash data in the region, a proposed queue warning system design, and a computer simulation of different components of the queue warning system. The preliminary findings from the safety analysis and simulation model show suggest that a queue warning system may be able to address some of the issues on the freeway.

Appendix A

VAP Code for the Queue Warning System

```
PROGRAM QWS;
CONST
    DET1 = 1,
    Occup_Rate1 = 0.12,
    Speed_limit = 45 ;


/* ARRAYS */

/* SUBROUTINES */

/* EXPRESSIONS */

/* MAIN PROGRAM */

S00Z001:   IF NOT Init THEN
S01Z001:     Init := 1;
S01Z002:       Set_route( 17 , 1 , 10 ); Set_route( 17 , 2 , 1 );Set_route( 17 , 3 , 1);
Set_route( 17 , 4 , 1 );Set_route( 17 , 5 , 1 ) ; Set_route( 17 , 2 , 1 )
    END;
S00Z004:   IF occup_rate ( DET1 ) > (Occup_Rate1) THEN
S01Z004:     IF (Velocity( DET1 ) > 0) AND (Velocity( DET1 ) > Speed_limit/1.41)
THEN
S01Z005:     Set_route( 17 , 1 , 6 );
S01Z006:     Set_route( 17 , 3 , 2 );
             Set_route( 17 , 4 , 2 );
             Set_route( 17 , 5 , 2 );
     END;
    END.
```

Appendix B

VISSIM Results for Detector Location

Scenario	Test	Occupancy Rate	Speed	Avg Delay Time per Veh (s)	Avg Speed (mph)	Avg Stopped Delay per Veh (s)	Avg # Stops per Veh	Total Delay Tim (hr)	Total Travel Time (hr)		**Travel Time on IH-35 (1) FREEWAY TRAVEL TIME, s**	**Travel Time FWY - FRONT ROAD (weighted avg of 2-5)**	**Travel Time Front - Front (6)**		Inters 1 (weighted avg)	Inters 2 (weighted avg)	Inters 3 (weighted avg)	Inters 4 (weighted avg)	Inters 5 (weighted avg)
1	1	14.8	22.5	105.547	16.263	40.395	1.329	313.974	628.546		313.8	329.1402135	532.9		33.32295887	50.01640091	45.6006262	50.01015532	35.53471921
	2	15.5	20.6	134.025	14.201	44.497	1.906	374.601	664.693		379.9	381.1930289	574.5		32.47972117	48.82324094	46.89812253	53.16168446	34.69414859
	3	14.6	22.4	103.784	16.446	41.777	1.345	303.769	614.091		304.5	327.4607547	387.8		34.60564663	47.54213974	47.99404171	49.93275862	35.03551343
	4	15.5	20.3	136.064	14.082	41.34	1.781	392.96	692.438		391.5	389.6172073	524.1		33.04890909	47.13317972	41.87824818	51.08530752	35.11769182
	5	15.1	21.7	96.226	16.974	39.082	1.154	278.868	583.583		318.0	318.0377309	526.0		32.69532595	46.31061947	46.37232274	49.54647137	35.19391586
	6	14.2	22.1	112.893	15.734	40.788	1.354	325.852	631.635		335.9	340.1460459	549.9		32.47555706	46.97303371	46.58599703	52.86192308	35.62709924
	7	14.2	23	117.731	15.382	44.936	1.499	346.686	658.016		330.2	343.2073604	577.3		32.691086	50.01640091	45.6006262	50.01015532	35.53471921
	AVG	**14.8**	**21.8**	**115.181**	**15.583**	**41.831**	**1.481**	**333.816**	**639.000**		**339.1**	**346.97176**	**524.6**		**33.045601**	**48.116431**	**45.84714**	**50.9440651**	**35.2482582**
2	1	15	21.1	110.418	15.845	41.276	1.342	313.926	612.092		328.1	340.6295082	499.3		33.07335	44.86856492	46.85931275	50.5920000	34.9417210
	2	14.5	21.6	100.368	16.642	41.087	1.233	294.162	602.705		301.3	305.0338221	416		33.6118068	48.24458874	46.95922473	54.13023256	34.20083574
	3	14.5	22.3	107.427	16.141	40.833	1.255	314.939	626.345		319.2	329.8284834	524.6		33.59325422	46.100000	47.29637717	49.87514863	34.1342097
	4	15.2	22.2	109.761	15.912	40.93	1.462	315.137	617.533		332.5	333.4677326	395.3		33.14385298	45.70176211	45.13100394	52.32324393	34.41910112
	5	14.4	22.7	110.578	15.948	44.158	1.47	325.525	642.399		317.5	333.6941876	409.3		33.14838902	45.60677201	47.2600779	52.07471264	34.55722949
	6	15.5	21.6	119.945	15.19	40.981	1.53	342.043	641.935		358.0	354.1075524	347.9		32.15072376	50.21753247	45.49940974	51.30417722	34.44388907
	7	15.3	21.1	114.152	15.588	42.959	1.372	334.052	641.681		328.3	347.2940361	657.8		33.04851117	46.23275488	47.58867282	54.41342105	36.10645669
	AVG	**14.9**	**21.8**	**110.378**	**15.895**	**41.746**	**1.381**	**319.969**	**626.384**		**326.4**	**334.86505**	**464.3**		**33.109984**	**46.710282**	**46.656297**	**52.101848**	**34.6862061**
3	1	14.8	22.5	105.547	16.263	40.395	1.329	313.974	628.546		313.8	329.1402135	532.9		33.32295887	50.01640091	45.6006262	50.01015532	35.53471921
	2	14.2	22.5	109.465	16.04	39.419	1.347	316.9	625.743		329.0	329.8337209	494.9		32.25718731	48.04509346	44.10045045	51.6354717	35.21223575
	3	13.6	23.9	108.625	16.107	39.745	1.386	318.303	630.448		326.0	333.3339793	478.3		33.70754119	46.100000	47.29637717	49.87514863	34.1342097
	4	14.5	21.6	100.368	16.642	41.087	1.233	294.162	602.705		301.3	321.3332	416.0		33.6118068	48.24458874	46.95922473	54.16124031	34.20083574
	5	14.2	23.4	102.203	16.514	37.908	1.274	295.509	601.023		315.4	325.2673469	430.0		32.54795918	45.59346847	41.74955179	49.3814070	34.98644724
	6	14.4	22.8	104.14	16.304	40.17	1.272	304.06	609.435		316.6	326.4514877	595.4		32.7674938	48.23568182	46.29795819	49.55573123	35.51179884
	7	14	23.3	94.368	17.215	38.96	1.173	278.961	593.228		294.7	307.914321	462.8		33.67599754	140.5825328	44.20708434	51.85575916	34.35500483
	AVG	**14.2**	**22.9**	**103.531**	**16.441**	**39.669**	**1.288**	**303.124**	**613.018**		**313.8**	**324.75347**	**487.2**		**33.127278**	**60.973967**	**45.173039**	**50.924988**	**34.847893**
4	1	14.3	22.7	100.09	16.787	38.24	1.177	295.072	609.679		310.2	316.0496749	449.1		34.64219128	46.600000	42.93960446	51.6960733	33.95617581
	2	15.2	22.2	109.761	15.912	40.93	1.462	315.137	617.533		332.5	332.6708494	395.3		33.14385298	45.70176211	45.13100394	52.32324393	34.0941573
	3	14.1	23	105.312	16.305	39.858	1.275	308.682	619.597		319.7	323.7880202	473.9		33.8856177	47.08156566	45.486727	51.30180072	34.22254112
	4	15.4	20.7	102.376	16.43	40.872	1.381	292.823	592.682		313.6	322.28220	599.7		33.53345818	48.58344086	46.80164809	51.8319236	33.02410072
	5	13.6	23.9	108.625	16.107	39.745	1.386	318.303	630.448		326.0	333.3339793	478.3		33.38496526	47.89557522	44.98826479	51.30206718	35.55060127
	6	15.5	20.3	136.064	14.082	41.34	1.781	392.96	692.438		391.5	389.6172073	524.1		33.04890909	47.133180	41.90374696	51.08530752	35.11769182
	7	14.2	22.9	121.858	15.05	43.576	1.596	351.593	654.328		354.9	356.7692086	777.1		32.63565324	47.37609195	46.87056452	50.8970000	34.7981180
	AVG	**14.6**	**22.2**	**112.012**	**15.810**	**40.652**	**1.437**	**324.939**	**630.958**		**335.5**	**339.21588**	**528.2**		**33.4678068**	**47.1959451**	**44.8745085**	**51.4910595**	**34.3947694**
5	1	14.6	21.6	111.25	15.882	40.978	1.369	325.529	636.336		330.8	339.9496635	366.9		33.75396226	50.31291759	45.36264368	53.48954082	33.76346092
	2	14.7	21.3	117.923	15.346	45.294	1.523	344.238	651.493		328.5	332.4657742	567.1		33.2355198	49.44110855	46.44116816	54.0007177	34.39927922
	3	14.1	23.1	101.495	16.674	39.278	1.224	295.972	607.647		308.6	319.6279292	504		34.28974843	48.81576355	46.70258835	51.1984456	33.3808978
	4	14.3	22.3	105.747	16.288	41.182	1.363	311.337	623.915		312.8	327.9716931	567.4		33.21107748	47.96378132	47.59463583	50.85154242	34.16697068
	5	13.8	23.7	106.191	16.281	41.374	1.397	311.937	624.885		317.7	322.1620506	545.6		32.05800733	46.631090	47.81293060	51.48520345	33.315948
	6	14.6	22.1	106.719	16.171	38.962	1.26	311.679	620.158		323.7	330.0268831	557.6		33.36415441	46.66745843	45.18921326	51.48322904	34.12900596
	7	14.2	22.1	112.893	15.734	40.788	1.354	325.852	631.635		335.9	340.1460459	549.9		32.73306097	46.97303371	46.58599703	52.86192308	35.62709924
	AVG	**14.3**	**22.3**	**108.888**	**16.054**	**41.122**	**1.356**	**318.078**	**628.010**		**322.6**	**330.33572**	**522.6**		**33.2350758**	**48.1150219**	**46.5270253**	**52.1958003**	**34.1118088**

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